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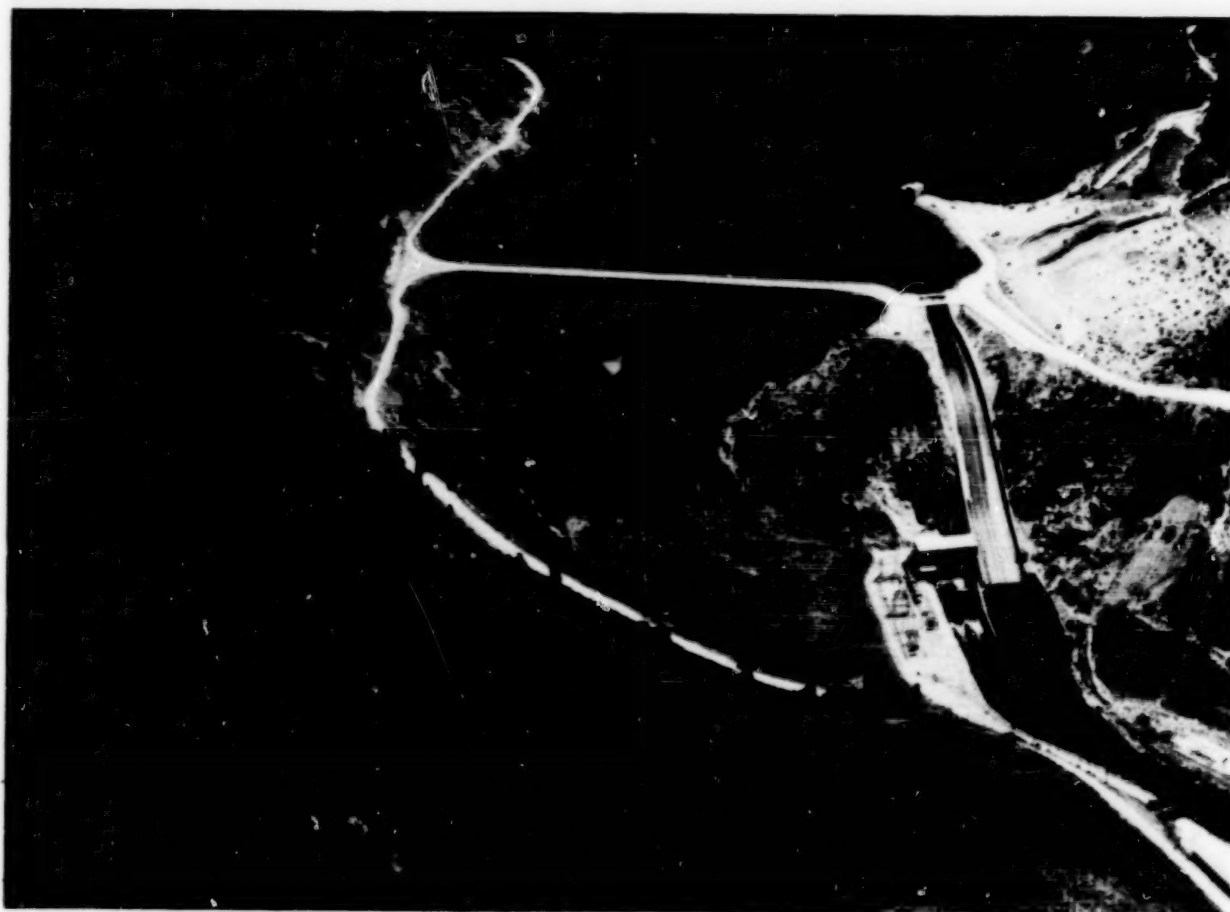
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PHYSICAL IMPACTS OF SMALL-SCALE HYDROELECTRIC FACILITIES AND THEIR EFFECTS ON FISH AND WILDLIFE



Fish and Wildlife Service

U.S. Department of the Interior

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PHYSICAL IMPACTS OF SMALL-SCALE HYDROELECTRIC FACILITIES
AND THEIR EFFECTS ON FISH AND WILDLIFE

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I

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II

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PREFACE

This manual provides an introduction to small-scale hydroelectric (<30 MW) technology and its impacts on fish and wildlife and their habitats for fisheries or wildlife biologists or other nonengineer readers. The text emphasizes the technical aspects of small-scale hydro, with a very limited discussion of institutional, social, legal, and economic factors.

The technical detail included is sufficient to obtain a general understanding of how a particular device or system performs. However, the manual is not intended as a guide to the engineering or planning of hydroelectric projects. The environmental impacts of small-scale hydro are indicated, but not described in detail. This approach maximizes the appreciation of the breadth of potential impacts associated with small-scale hydro, while avoiding a level of detail that would not be of use to most readers. References to more specialized literature on particular fish and wildlife problems are included with each chapter.

Mitigation alternatives are listed at the end of each technical section in this report. A more detailed Mitigation Handbook was developed in conjunction with this manual to guide biologists in the selection of mitigation alternatives appropriate for the environmental impacts of small-scale hydroelectric development.

Questions or other correspondence regarding this impact manual and the companion mitigation handbook should be addressed to:

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EXECUTIVE SUMMARY

This manual contains information on the activities and equipment that comprise small-scale hydroelectric technology and reviews the potential impacts of small-scale hydro on fish and wildlife and their habitats. The manual is designed to provide guidance to persons reviewing applications for the development of sites capable of generating up to 30 MW of electricity in terms of the consideration of potential impacts on fish and wildlife resources.

Benefits of small-scale hydro include increased energy self-sufficiency, the dependability of the technology, and, occasionally, educational, historical, and fish and wildlife benefits. Serious conflicts can exist between the goals of increased small-scale hydro development and fish and wildlife. Of particular concern is the potential blockage of fish migration, loss or degradation of habitat, changes in the amount and pattern of instream flow, mortality and morbidity of fish passing through turbines and over dams, and the degradation of water quality.

Small-scale hydroelectric plants capture the energy of falling water in direct proportion to the amount of fall (head or elevation difference) and the discharge of the stream. Sites on perennial streams can offer a dependable source of electrical power; other types of sites include multiple use projects, such as lock and dam structures or water storage impoundments, canal drops, and pipe networks. Each type of small-scale hydro project has unique advantages and disadvantages and potential environmental impacts.

The construction activities needed to establish an operating small-scale hydro plant vary considerably depending on whether the project is new, restoration, or retrofit. Preconstruction activities include inspections of existing facilities, surveys, geological investigations, and, sometimes, minor road construction. Construction steps vary according to the type of small-scale hydro plant, but typically include dredging or flushing, landfilling, removal of vegetation, excavation, and concrete work. Dewatering, channelization, and flow diversion, both temporary and permanent, may occur during construction.

Dams and impoundments, spillways, intakes, waterways and their controls, turbines, the powerhouse and its auxiliary equipment including sub-stations and transmission lines make up the small-scale hydro plant. These components exist in many forms, and, in some types of plants, some of the possible components are absent or much reduced in relative size

compared to equivalent features in large-scale hydro plants. The principal impacts of small-scale hydroelectric facilities affect fish population through effects on migration, reproduction, and rearing and resident adult habitat. Birds and terrestrial animals also may be impacted from certain facilities, such as transmission towers and canals.

Hydroturbines suitable for small-scale use include the conventional impulse and reaction types, including Pelton, Cross-flow, Francis, and propeller designs. Recently, several unconventional turbine designs have been proposed especially for use in small-scale plants. Turbines of all types can injure and kill fish; the extent of the effect varies according to fish species and size, turbine design, turbine operating efficiency, and other factors. Predicting turbine impacts on fish is difficult because many of the possible combinations of turbines and fish have never been tested and because existing test results are inconclusive. Most of the unconventional turbine designs have never been tested in terms of resulting fish mortality, and their design often is sufficiently different from that of older turbines to make impact prediction based on existing data highly unreliable.

Small-scale hydroelectric projects operate in run-of-river, peaking, or seasonal store and release modes. The main concerns associated with these operational modes are alterations of the physical, chemical and biological features of habitat which can affect all life stages of fish and other species of concern. Instream flow alterations may lead to fish stranding and a reduction in the transport of nutrients, plankton, and sediments essential for the maintenance of downstream biological productivity. Adverse impacts may also result from routine maintenance of small-scale hydro facilities which typically involves cleaning and disposal of debris, trimming of site vegetation, and equipment overhaul. Required maintenance that necessitates extensive site work may result from floods, sediment accumulation, or structural defects and may have serious impacts if not accomplished with care.

More than 100 possible types of environmental impacts have been associated with small-scale hydroelectric technology. Not all projects will have all of these impacts, however. Major impacts that are common to small-scale hydro sites in the United States include:

1. Blockage (and mortality) of both upstream- and downstream-migrating fish by dams, diversion structures, turbines, spillways, and waterways;
2. Alteration of stream and riverine habitats, natural lakes, riparian areas and wetlands by inundation, dewatering, channelization, and filling;
3. Changes in water quality, including changes in sediment transport, dissolved oxygen, and water temperature;

4. Alteration of flow regimes, both increases and decreases, which make otherwise suitable riverine habitats unfit for aquatic invertebrates, fish, amphibians and reptiles, and possibly, dependent riparian species;
5. Fluctuating instream flows and reservoir levels, which make habitats too unstable for full utilization and may degrade water quality;
6. Disturbance of fish and wildlife and their habitats from construction activities, increased numbers of visitors to sites, road dust, oil and toxic waste spills, noise from some hydroelectric equipment, and site lighting, blasting, and waste releases;
7. Damage to terrestrial habitats and soils, disruption of runoff patterns related to road building and transmission line clearance, and creation of borrow pits and spoil disposal sites;
8. Long term changes in river hydrology, including possible changes in flow regime, the river's contribution to ground water, and evapotranspiration due to alterations of stream-flow patterns that will have far reaching implications to fish and wildlife; and
9. Changes in recreational use and visitor access, which may increase fish and wildlife exploitation rates and forest fire danger.

Impact assessment is highly site-specific and requires an orderly approach to information gathering and analysis. Alternative actions designed to mitigate the impacts of small-scale hydro may involve tradeoffs among different fish and wildlife resource management objectives.

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ABBREVIATIONS AND SYMBOLS

ac	-	acres
AC	-	alternating current
cm	-	centimeter
cm ²	-	square centimeter(s)
cfs	-	cubic feet per second
DC	-	direct current
EPA	-	Environmental Protection Agency
FERC	-	Federal Energy Regulatory Commission
ft	-	foot or feet
ft ²	-	square foot or feet
fps	-	feet per second
FWS	-	U.S. Fish and Wildlife Service
gal	-	gallon
GW	-	gigawatt
H	-	head
ha	-	hectare
hp	-	horsepower
Hz	-	Hertz
in	-	inch(es)
in ²	-	square inches
kg	-	kilogram
kV	-	kilovolt
km	-	kilometer
kW	-	kilowatt
kWh	-	kilowatt-hour
l	-	liter
lb	-	pound
m	-	meter
m ²	-	square meter(s)
MW	-	megawatt
mg	-	milligram
mi	-	mile
psi	-	pounds per square inch
s	-	second
SSH	-	Small-scale hydroelectric
Q	-	discharge (flow rate)
σ	-	sigma

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1. INTRODUCTION

The upsurge in interest in alternative energy sources following the oil "shocks" of the early and late 1970's focused on hydroelectric power as an historically proved, but underexploited, source of renewable energy. The National scope of enthusiasm for hydroelectric projects, as well as the fact that rivers and lakes often cross State borders, necessitated both Federal and State participation in the planning and operation of hydroelectric projects. The purpose of this manual is to bring together pertinent information for assessing the potential environmental impacts of small-scale hydroelectric (SSH) projects.

1.1 OBJECTIVE AND SCOPE OF THE MANUAL

This manual is designed to meet the special needs of U.S. Fish and Wildlife Service (FWS) and Environmental Protection Agency (EPA) field level personnel, who have a legal responsibility to review the numerous SSH projects being developed or proposed for development throughout the country. This manual and its companion Mitigation Handbook should prove useful to personnel in other Federal agencies and in State fish and game agencies who have similar responsibilities towards fish and wildlife resources potentially affected by SSH technology; they should also be useful to the private sector.

FWS and EPA biologists and other assessment personnel face similar challenges: (1) the time available for the review of projects is limited; (2) information that might be useful in an assessment is widely scattered or often cannot be obtained within the allotted review period; (3) biologists often lack background or experience in pertinent hydroelectric engineering concepts and terminology; (4) SSH projects vary tremendously in design concept, physical layout, and operational mode; and (5) regional differences in environmental factors influence the engineering approach chosen and its effect on fish and wildlife and their habitats.

The complex and constantly changing Federal, State, and local regulations and ordinances applicable to SSH development are not discussed. Instead, the report emphasizes the technical aspects of SSH projects and their impacts on the natural environment. This manual explains, in a general way, how the various pieces of equipment used in SSH projects work, how they are assembled into power plants, and how their characteristics relate to environmental impacts. In addition to pointing out the potential environmental impacts resulting from SSH equipment and their

operation, the manual discusses how impacts may have complex interrelationships, which may lead to unexpected consequences. It is hoped that the discussion will help the reader organize his/her thinking about a particular SSH project under review, and stimulate them to question the hydro developer or outside experts as needed to clear up any doubtful aspects of the project being reviewed. To complete the discussion of environmental impacts of SSH projects, mitigation alternatives are listed; specific mitigation measures are provided in the companion Mitigation Handbook.

Environmental impacts affecting fish and wildlife are the primary subject of this manual. An environmental impact, as defined here, is an "observable effect" on fish, wildlife, or their habitats. All the major environmental impacts of SSH projects, both positive and negative, are discussed in this manual. Generally, this means that only primary (direct) impacts of SSH equipment and activities can be considered; however, some of the most important secondary impacts are also discussed. Because the actual magnitude of an environmental impact depends on site-specific conditions, no attempt is made in this manual to suggest relative magnitudes of impacts, except when impacts can be generalized safely over a large number of SSH projects.

Information pertinent to SSH development in the United States, including Alaska, is included in this manual. Small-scale hydro is defined as projects with total project power of < 30 MW generating capacity. This amount of power is sufficient for the normal needs of about 15,000 people (J. Hanson, pers. comm.). The definition of SSH used in the Public Utility Regulatory Policies Act (PURPA: PL 95-617, November 1978) is 15 MW generating capacity. Another term, considered by many people to be synonymous with SSH, is "low-head" hydro, which has been defined by the Department of Energy as 20 m (66 ft) of fall (U.S. Army Corps of Engineers 1979). While both the terms small-scale and low-head generally refer to relatively small hydroelectric projects, the two terms are definitely not exchangeable in all situations. A low-head plant on a river of high discharge could easily produce more than 30 MW of power, whereas developments of more than 20 m head that produce less than 30 MW, or even 15 MW, are common, particularly in mountainous areas.

The present work covers all the common configurations of SSH plants within the contiguous United States and Alaska, except for pumped storage and tidal power systems.

1.2 SOURCES OF INFORMATION

The information on SSH technology and its environmental impacts contained in this manual was assembled from published and unpublished literature; consultations with engineers, biologists, and government personnel; manufacturers' literature; and presentations at professional conferences. Much of the published literature is listed at the end of each chapter in

this manual. Direct contacts with people working in the SSH field may be more productive than literature research when attempting to gather information about specific concerns because SSH is evolving so rapidly in technological, regulatory, and economic aspects.

1.3 APPLICATION OF THE MANUAL

1.3.1 Manual Organization

This manual deals with the following four aspects of SSH projects:

- Opportunities and conflicts with other activities and resources (Chapter 2);
- Overview of SSH technology and description of the main types of SSH projects (Chapter 3);
- Purpose (and functioning) and impacts of construction activities, facilities and equipment, and operations and maintenance activities associated with SSH projects (Chapters 4-7); and
- Analysis of the interrelationships of impacts and comments on alternatives and mitigation approaches (Chapter 8).

1.3.2 Procedure for Users

This manual should be read in its entirety in order to understand the relationships between different aspects of SSH technology and the environment. The manual also can be consulted on a case-by-case basis to assess potential impacts or individual components of particular projects under review.

Chapters 2 and 3 should provide a general orientation to the subject of SSH and its role in the National energy and environmental quality picture. Chapters 4 through 7 provide detailed information on the functioning of each component of the SSH system, with the associated environmental impacts described. These chapters have the same format in order to assist the reader in relating particular components of a SSH project to their environmental impacts. In each case, the "hardware" is described first; followed by the associated engineering and economic considerations and tradeoffs; and, finally, the environmental effects, environmental tradeoffs, and mitigation alternatives appropriate to that equipment or procedure. The last chapter of the manual (Chapter 8) describes the complex environmental impact interrelationships that often exist in SSH projects.

1.4 REFERENCES

- Hanson, J. 1983. Philadelphia Electric Co., Philadelphia, PA. Pers. Comm.
- U.S. Army Corps of Engineers. 1979. Feasibility studies for small-scale hydro-power additions: a guide manual. The Hydrologic Engineering Center, Davis, CA, and the Institute for Water Resources, Fort Belvoir, VA. DGE/RA-0048. 6 vol.

2. OPPORTUNITIES AND CONFLICTS OF SMALL-SCALE HYDROELECTRIC DEVELOPMENT

North America has always had an enormous potential for generating power from water, and many early manufacturing concerns were driven by water power. In America, during the 17th and 18th centuries, the power output of most water wheels was less than 8 kilowatts (kW) each (Malone 1982). The first hydraulic turbines appeared in the period 1820-1840. As a result of improvements in dam, canal, and hydraulic machine technology, there was a large expansion in industry, especially in the Northeast. By 1870, the average power output from a waterwheel had increased to 17 kW (Malone 1982).

By the 1890's, the use of water power to generate electricity was becoming widespread. Many potential hydro sites, not economically feasible for mechanical power, became attractive. The power could be transmitted over relatively long distances with little loss of energy, and one station could supply a number of mills, eliminating the need for an elaborate network of canals (Malone 1982). Small-scale hydroelectric dams were soon common all over the northeastern United States, with many others in different parts of the country. By 1930, most of the mills in New England either generated their own electricity or bought it from utilities. During the early 20th century, there were many SSH facilities built in the far West along the western slope of Sierras. In the Southeast and West, many large-scale hydroelectric projects were built during the Great Depression as public works projects.

Eventually, fossil fuel-powered steam generating plants became as economical as existing hydroelectric dams and more economical than developing marginal sites. During this period (coinciding with the decline of the northeastern textile industry), many small and old hydro works in the eastern U.S. were abandoned. By the mid-20th century, fossil fuel and nuclear plants were producing relatively inexpensive electricity to supply the rapidly increasing demand for power. By 1978, hydro power made up only about 13% (or nearly 60 million kW) of the total electricity generated, and there were approximately 45,000 small dams in the United States that were not producing hydroelectric power (Heutter 1978).

In the 1970's however, escalation in the cost of fossil fuels, supply uncertainties, higher building costs for new thermal electric generation plants, and increasing public concern about the safety of nuclear plants made alternative energy sources, including small-scale hydroelectric, appear much more attractive on economic, social, and environmental grounds.

The size of the small-scale hydroelectric energy resource is difficult to estimate due to a number of complicating factors. Regardless of the actual size of the resource, however, it is limited in practical terms by the economic feasibility of the sites. Many sites are not suitable for development at today's energy prices. According to the U.S. Army Corps of Engineers (1981), at least 2,000 sites of less than 15 MW generating capacity could become economically feasible during the next few years; many more feasible sites exist in the 15-30 MW range. Small-scale hydro capacity at existing dams is shown in Figure 1. It is evident that most development potential is in two regions: the Pacific/Western Rocky Mountain States (FWS Region 1) and the Northeastern States (FWS Region 5). Most of the projects now under active consideration are less than 5 MW in total rated capacity. There is some additional capacity in the very small (mini-hydro) range that is not evident from Figure 1 because developers of small private projects often do not prepare formal economic feasibility studies; therefore, their projects are not included in resource surveys limited to economically feasible projects.

Aided by attractive Federal incentives under PURPA (Public Utilities Regulatory Policy Act) legislation, which requires utilities to transmit and purchase electricity produced at high rates, allows developers to claim, for development, SSH sites they do not own, and gives substantial deductions from Federal taxes, small hydro projects became very popular in the early 1980's (Table 1). Recently, activity has slowed somewhat, probably due to a combination of reduced power demand during a recession, high interest rates, and decreases in the cost of competing fuels. A large amount of site assessment and design work was done in the 1970's, however, which makes it likely that the number of active SSH projects would increase rapidly should there be another energy "crisis."

The remaining sections of this Chapter summarize the most important opportunities presented by the growth of small-scale hydroelectric development and the conflicts with other resources that this technology may present.

2.1 OPPORTUNITIES PRESENTED BY SMALL-SCALE HYDRO

2.1.1 Economic, Engineering, and Social Opportunities

Hydroelectric power is likely to become a more desirable power source for the United States as other energy sources become more costly and less available. Subject to the natural fluctuations in stream discharge, uncertainties of supply as a result of strikes, embargoes, and technological problems are less; local autonomy in energy is preserved; and many of the problems of pollution, waste disposal, and land use associated with other energy technologies are reduced or not present with hydropower. An established hydro site can have a very long service life. Figure 2 portrays the Great Falls Hydroelectric Facility located in the Passaic River in Paterson, New Jersey. Water power from this site was first developed in 1794. The present plant, which will be retrofitted, was built in 1914 (U.S. Army Corps of Engineers 1979).

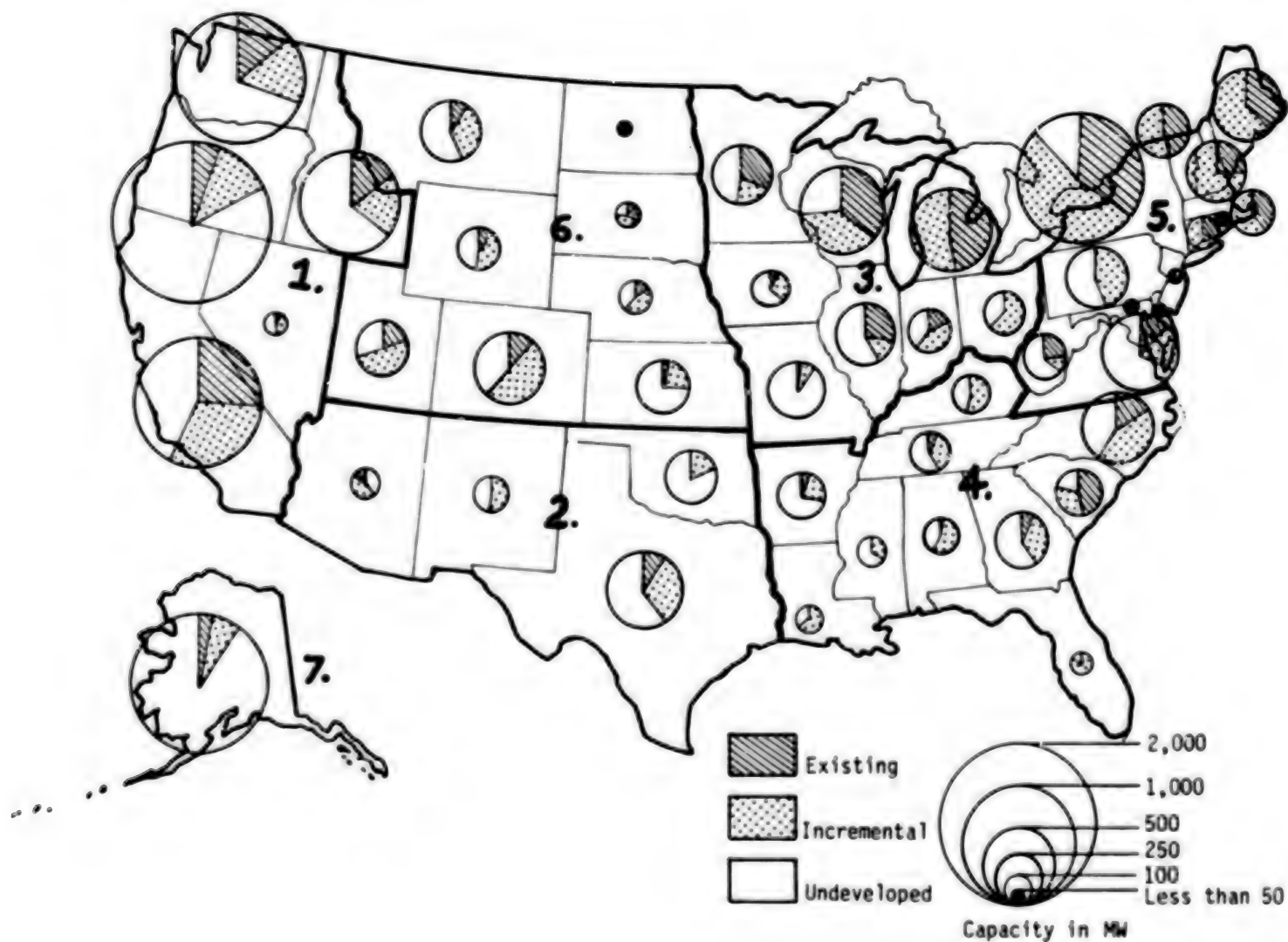


Figure 1. Existing, incremental, and undeveloped small-scale hydroelectric resources in the conterminous United States and Alaska (American Society of Civil Engineers, Boston Sect. 1980). Numbered regions are U.S. Fish and Wildlife Service regions.

Table 1. Hydroelectric project applications^a and decisions made by FERC^b in fiscal years 1977-1983^c (Corso 1982; Office of Public Information, FERC, pers. comm.).

Action	1977	1978	1979	1980	1981	1982 ^d	1983
Applications	264	182	276	772	2,292	1,289	935
FERC decisions	222	169	290	578	1,657	1,219 ^e	--

^aIncluding licenses, preliminary permits, exemptions, and other types.

^bFederal Energy Regulatory Commission.

^c1 October to 30 September.

^d1 October 1981 to 30 April 1982.

^eIncludes authorization of over 275 projects since 1980 that propose new generating capacity.

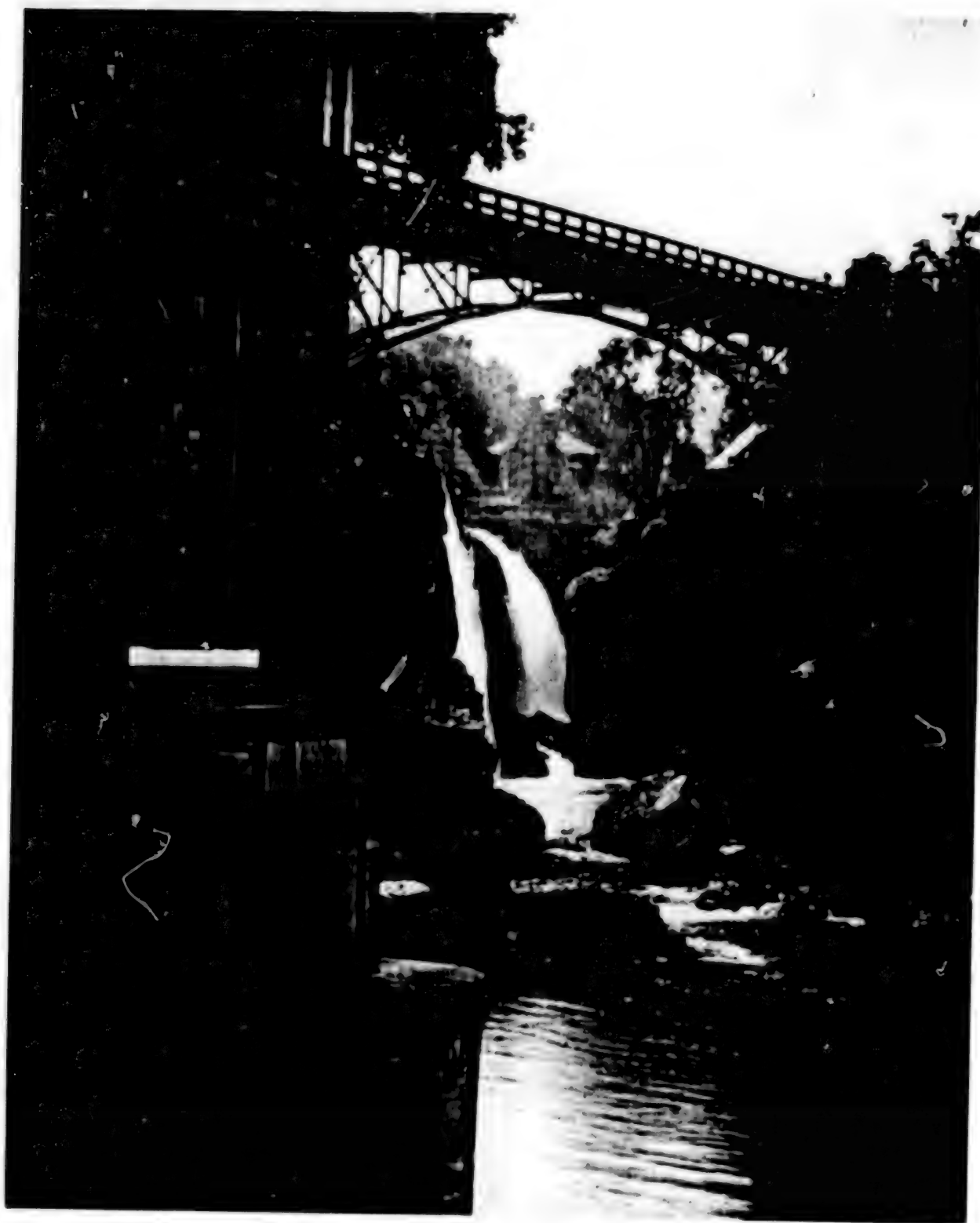


Figure 2. Powerhouse of the Great Falls Hydroelectric Project below the Great Falls of the Passaic River, Paterson, New Jersey (T. Lloyd Associates).

Most of the hydroelectric facilities of the future will be small compared to the large plants presently supplying power in the Northwest and the South. It has been estimated that the electricity needs of 14-20 million people could be supplied from small to intermediate facilities at sites that have already been identified (Heutter 1978).

From a technical standpoint, SSH has the advantage of being a well understood, proven technology, with an established infrastructure of engineers, consultants, and suppliers. Project development can proceed rapidly in most cases. SSH plants are capable of instantaneous start-up, which makes them well suited for a reserve power role in energy-short regions. SSH can often be used to advantage at remote sites where long transmission lines from a major grid would be too expensive or impractical and where the cost of transporting fuel for thermal electric generation is prohibitive. Small-scale hydro is well suited for seasonal operation at very small sites, such as ranches, lodges, and lumber camps, as long as the season of maximum flow coincides with the season of greatest need or sufficient water storage is provided and sufficient flow is available for competing and existing water users; e.g. agriculture, fisheries, etc.

The cost of generating electricity can be divided into two components: capital costs and operating costs. For thermal electric generating plants, operating expenses consist mainly of fuel costs. When fuel costs are unpredictable (and sometimes rapidly increasing), it becomes more attractive to invest in production facilities with relatively high capital costs, provided that future operating costs can be reduced or made independent of fuel prices. Hydropower is such an investment.

Although the specific capital costs for hydropower depend on the physical conditions at a site, the cost of construction per kilowatt of capacity is usually higher for a hydro facility than fossil fuel plants. However, hydro has a significant advantage over fossil fuel and nuclear plants in terms of operating costs because of the minimal fuel costs. In addition, hydroelectric facilities last longer than other electric power plants and have a relatively simple operation that requires fewer operating personnel and less maintenance expense. Annual operation and maintenance costs usually vary from 2% to 5% of the total construction costs of a hydroelectric project (U.S. Army Corps of Engineers 1979). The lifetime economics of hydroelectric generation is competitive (depending on site-specific costs) with other forms of energy production at many locations. For example, small projects are often economically feasible in heavily oil-dependent utility territories or at sites where existing civil facilities reduce SSH construction costs.

Electrical power can be used either for some direct purpose, such as running a factory, a pumping system, or some agricultural activity, or it can be sold to a utility for general distribution through a grid system. The latter use is the one most often proposed for SSH projects.

The demand for electricity from a typical utility varies fairly predictably over the course of a day and the days of the week (Fig. 3), as

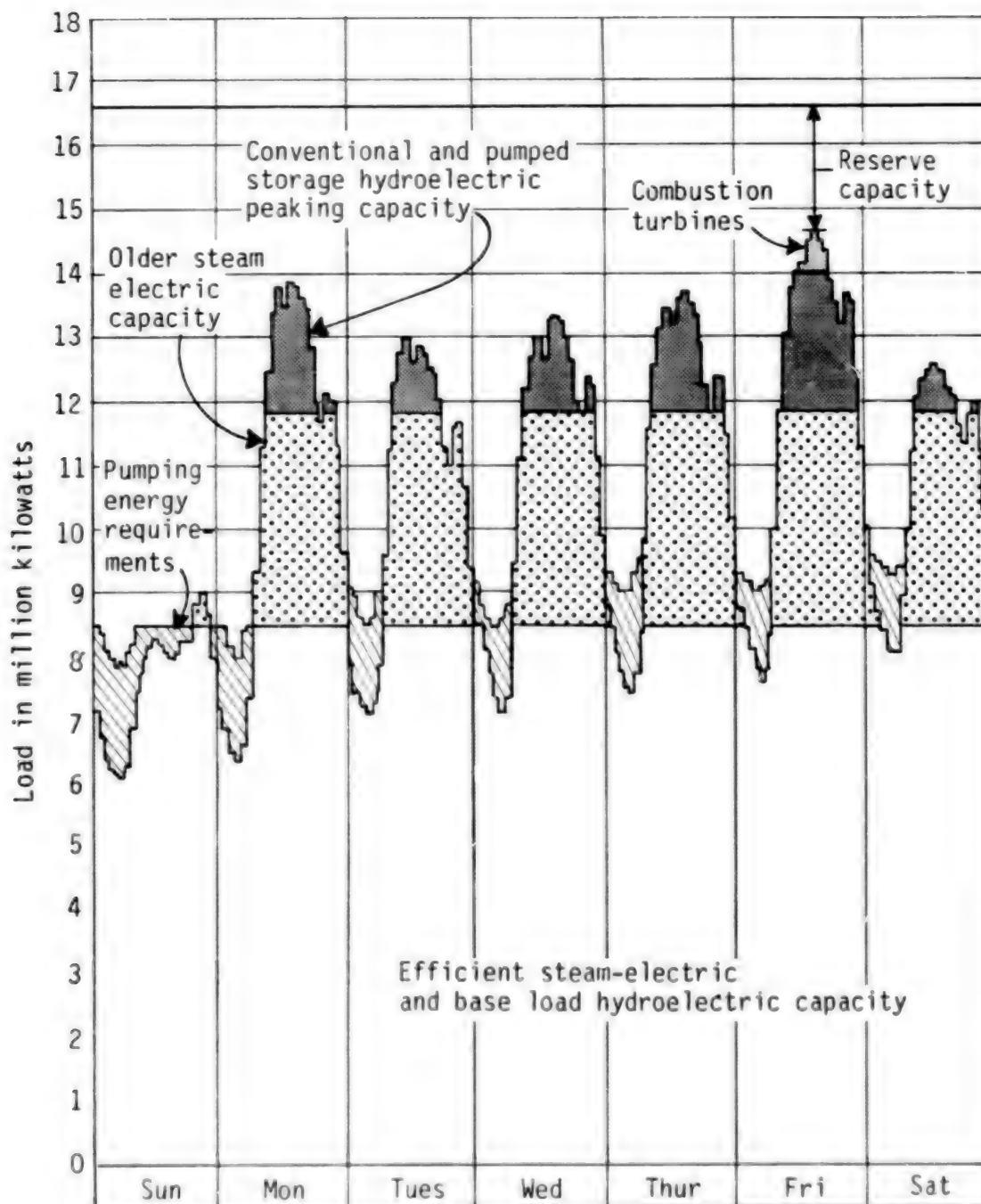


Figure 3. Weekly load curve of a large electric utility system (U.S. Army Corps of Engineers 1979).

well as the seasons of the year. The demand that must be supplied continuously is called the baseload; usually nuclear or coal-fired thermal plants supply the baseload because they operate most efficiently at a steady, large output and require long lead times to start up and cool down. Large, main stream hydroelectric plants also help meet the baseload demand. Small hydro plants also can produce electricity continuously as long as flows are steady, but are technically well suited to satisfy peak demands because rapid changes in output can be made by regulating the discharge through the turbines.

The market value of the electricity from a hydro plant normally is related to the costs of competing sources of electric power although, in some States, the value of hydroelectric output is now set by law. When costs for meeting peak daily or seasonal demands by fuel-consuming steam driven generators are high, as is often the case where fuel is expensive or the existing thermal plants are small and inefficient, SSH may plan an effective role in replacing these plants. Thus, store and release (peaking, see Chapter 7.2) operation of a SSH plant may be its most valuable role economically, provided that there is sufficient reservoir capacity available.

On the other hand, site limitations may make operating in a peaking mode impractical. These constraints may include the requirement to maintain reasonably steady flows for fish and wildlife, recreation, or downstream water consumers. Even then, SSH may be economically feasible, although perhaps not as profitable.

Small hydro plants can be used to provide additional economic benefits from facilities used primarily for other purposes, such as when electric power generated in irrigation canals is used to pump water out of the canal into the fields. In certain circumstances, a SSH facility may provide historical and educational benefits, such as when a former hydroelectric plant or water-driven industrial mill is restored for use; this activity is particularly common in New England. Recreational activities may be improved if an impoundment is created or when a damsite is provided with access roads, which also benefits boaters, hunters, and fishermen.

2.1.2 Fish, Wildlife, and Environmental Opportunities

SSH is not totally environmentally harmless. There are, however, some positive aspects to this technology that should not be overlooked when comparing it to other energy sources. When a dam is constructed new warm water fish habitat or wetlands often are created. These may be beneficial in parts of the country where open water is scarce. Likewise, a dam can be used to regulate flows to the benefit of fish and wildlife, as in creating a tailwater fishery. In some places, the fish-blocking effect of a dam (a negative impact where anadromous fish are involved) can be used to keep fish populations separate for management purposes. When a proposal is made to rehabilitate an existing facility, improvements in fish and wildlife protection at the site may be included as a condition for permitting SSH development, resulting in an overall improvement in fish and wildlife

populations (Fig. 4). SSH may be the least destructive among various energy alternatives for a given site and, therefore, contribute to reducing environmental degradation from other causes. However, each site must be considered individually to determine if SSH is less environmentally damaging than competing energy options.

2.2 CONFLICTS OF SMALL-SCALE HYDRO WITH OTHER USES

2.2.1 Fish and Wildlife Conflicts

Based on experience with various hydro projects and other activities that affect rivers, several important concerns associated with SSH projects have been identified. The most significant SSH impacts can be grouped as follows:

1. Blockage (and mortality) of both upstream- and downstream-migrating fish by dams, diversion structures, turbines, spillways, and waterways;
2. Alteration of stream and riverine habitats, natural lakes, riparian areas and wetlands by inundation, dewatering, channelization, and filling;
3. Changes in water quality, including sediment transport dissolved oxygen, and water temperature;
4. Alteration of flow regimes, both increases and decreases, which makes otherwise suitable riverine habitats unfit for aquatic invertebrates, fish, amphibians, and reptiles, and, possibly, dependent riparian species;
5. Fluctuating instream flows and reservoir levels, which make habitats too unstable for full utilization and may degrade water quality;
6. Disturbance of fish and wildlife and their habitats from construction activities, increased numbers of visitors to sites, road dust, oil and toxic waste spills, noise from some hydroelectric equipment, and site lighting, blasting, and waste releases;
7. Damage to terrestrial habitats and soils, disruption of runoff patterns related to road building and transmission line clearance, and creation of borrow pits and spoil disposal sites;
8. Direct effects of transmission lines on fish, wildlife and their habitats.
9. Long term changes in river hydrology, including possible changes in flow regime, the river's contribution to ground



Figure 4. Fish lift at Holyoke Dam, Holyoke, Massachusetts (Boyd Kynard, Cooperative Fisheries Research Unit, University of Massachusetts, Amherst, Massachusetts). This is an example of a mitigative measure that can be made a condition for establishing SSH at an old dam to achieve an improvement in existing fishery resources or to correct a previously unmitigated impact.

water, and evapotranspiration due to alterations of stream-flow patterns that will have far reaching implications to fish and wildlife; and

10. Changes in recreational use and visitor access, which may increase fish and wildlife exploitation rates and forest fire danger.

Adverse impacts of SSH development and operations may affect fish and wildlife either directly or indirectly. Direct effects include actual mortality or disturbances or destruction of habitat to the point that a species of fish or wildlife cannot live in the area. Indirect effects include habitat alterations or disturbances that make an area less suitable to a species of fish or wildlife or that change predator/prey and competitive relationships to the point that population levels or productivity are adversely affected.

2.2.2 Other Resource Conflicts

This manual is not intended to consider environmental impacts other than those effecting fish and wildlife. However, for the sake of completeness, it is worth mentioning that SSH can be in conflict with human activities and systems as well. Recreation may be negatively impacted by flow fluctuations or seasonal decreases caused by operational procedures required for power generation. Such popular activities as whitewater rafting and kayaking could be adversely affected by low flows or sudden changes in discharge. The aesthetic and recreational values of rivers and streams, historic sites such as canal locks, and pond and wetland shorelines could be affected by alterations of flow due to SSH projects. Small-scale hydro may affect flows to the detriment of other water users even though no water is consumed; for example, by storing water during irrigation or stock watering seasons, or by diverting water and cutting off a user whose property lies in the affected portion of the stream. None of these conflicts with other valuable uses is a certainty for every SSH project; the existence of a conflict must be determined by a careful site-specific analysis of water needs in relation to planned hydro operations.

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3. OVERVIEW OF SMALL-SCALE HYDROELECTRIC TECHNOLOGY

In this chapter, the principles underlying the generation of electricity from falling water are outlined and the major general types of SSH plants are described. Regional and environmental considerations are discussed for each of the different types of SSH projects. The discussion below is a general introduction to the more detailed discussion in the following four chapters.

3.1 HYDROPOWER PRINCIPLES

Water acquires potential energy during the hydrologic cycle when it is raised to an elevation above sea level, from which it falls as rain. Run-off, flowing to the sea, expends much of its potential energy as kinetic energy in collisions with stream banks and bottoms, in turbulence, and in carrying a sediment load. Hydroelectric plants capture some of the energy of water as it falls from a high potential energy level to a lower one. The water falls through a "wheel," or turbine, which converts the potential energy into rotating mechanical (kinetic) energy; the generator is used to change the mechanical energy into electrical energy.

The measure of the total amount of energy available over a given stream reach is the difference in elevation (gross head) times the amount of the discharge. In other words, both the height through which the water falls and the amount of falling water contribute to the energy available at a given site. Neither all the head nor all the flow can be captured effectively in a hydroelectric plant. Plants normally are able to capture about 80% of the available energy (Creager and Justin 1950).

Comparatively simple formulas have been developed to calculate the power available at a given site. The standard formula¹ (Creager and Justin 1950) is:

¹The equivalent formula in conventional units is more familiar to American engineers:

$$P_{kW} = Q(H - h_f) e / 11.8$$

where P = power (kW)

Q = discharge (ft³/sec)

H = gross head between intake and draft tube (ft)

h_f = head losses within the system

e = a fraction for overall system efficiency, usually about 0.80

11.8 = a constant related to the weight of water.

$$P_{kW} = \frac{Q(H - h_f) e}{127.72}$$

where P = power (kW)

Q = discharge (l/sec)

H = gross head between intake and draft tube (m)

h_f = head losses within system ($H - h_f$ = net head)

e = overall system efficiency, usually about 0.80

127.72 = constant related to the weight of water

The term h_f , "head losses within system", represents friction, such as that created when water comes in contact with the walls of pipes, screens, and control valves within the hydroelectric equipment. The equation shows that, for a given head, power can be increased by reducing losses due to friction (i.e., the net head is increased), increasing the discharge, increasing overall system efficiency, or some combination of these actions. The most direct way to obtain more power is to increase the gross head by building a dam or increasing the height of an existing dam. Another way to obtain more power is to increase the flow by diverting more water through the hydropower system. Head losses can be reduced by optimal choices of design, equipment, and materials.

The developer of a hydroelectric energy project is interested in determining how much power can be obtained annually from a given site and the related costs. Plant capacity usually is less than the maximum amount that could be obtained at a particular site because it is not economically feasible to install extra capacity just to capture energy from an exceptionally rare flood. Figure 5 shows how natural discharge variations affect power output for three different installed capacities over the course of an average year (based on 10 years of data). Table 2 illustrates the fact that the amount of power available over an annual period is well below the amount of energy that hypothetically could be obtained if the turbines ran at full capacity 100% of the time. In this example, the percentage of the installed capacity that could be productively used will decrease as the installed capacity increases. This diminishing returns relationship is typical of hydroelectric sites; the challenge of a feasibility analysis is to determine the installed capacity that will yield the highest return on developer investment. It should also be noted here that the amount of flow available for power production will depend upon flow releases required to service downstream users and to meet minimum flow requirements imposed to maintain aquatic/wetland resources. The problem of matching the size of the SSH plant to the site is discussed further in Chapter 6, Turbine-related Impacts.

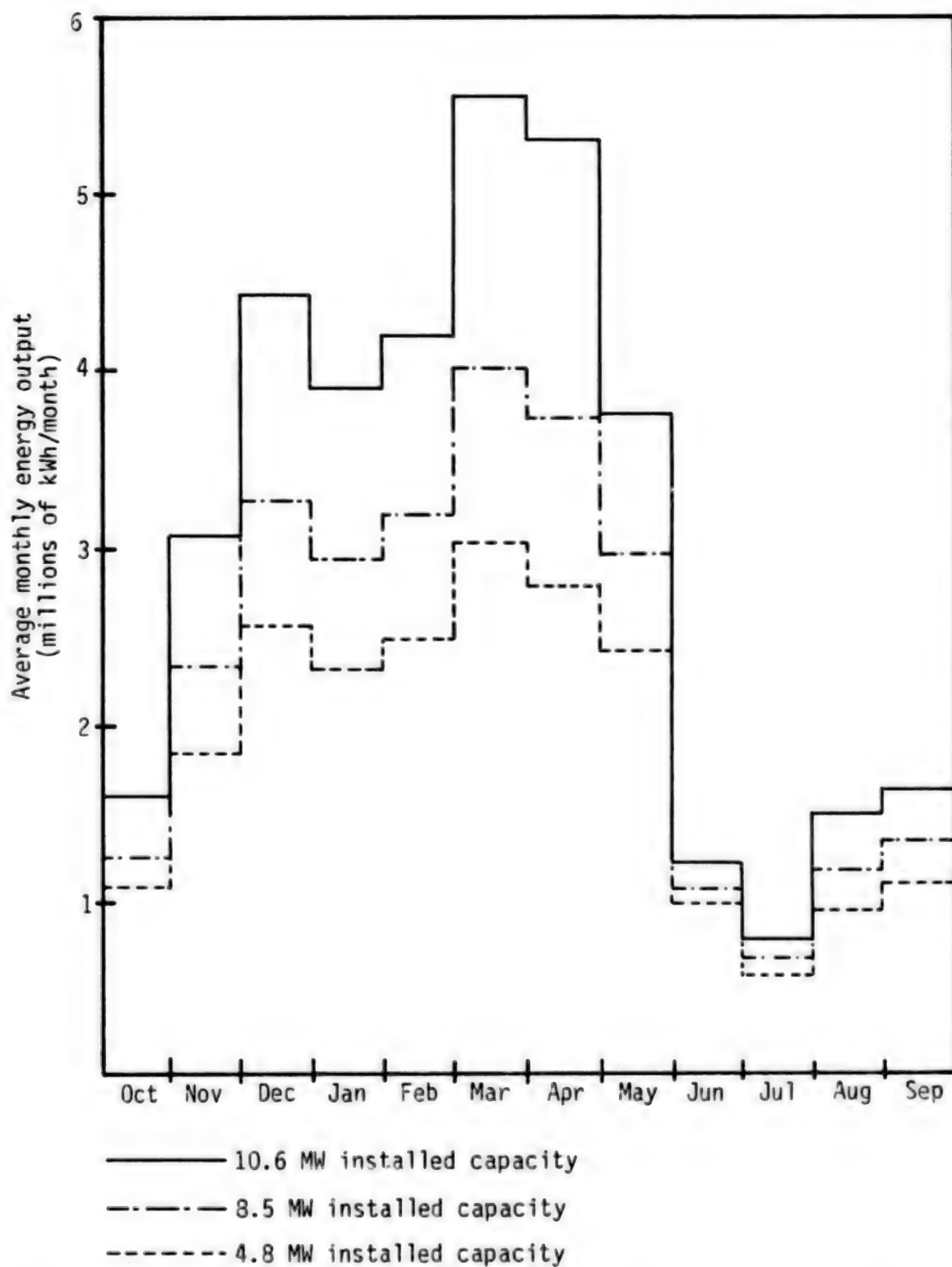


Figure 5. Pattern of estimated annual power output for three levels of installed capacity at the Great Falls of the Passaic River, New Jersey (U.S. Army Corp of Engineers 1979).

Table 2. Annual power production from a hydroelectric site at three different installed capacities. This is the same site as in Figure 5, the Great Falls of the Passaic River, Paterson, New Jersey (Data from U.S. Army Corps of Engineers 1979).

Installed capacity (MW)	Total hypothetical output (kWh) ^a	Actual projected output (kWh) ^b	Percentage of hypothetical output obtained	Gross income at \$0.06 per kWh
4.6	40,296,000	22,800,000	57	\$ 1,368,000
6.5	56,940,000	27,600,000	48	1,656,000
10.6	92,856,000	37,200,000	40	2,232,000

^aIf the plant ran all year (8,760 hours) at full rated capacity.

^bBased on the discharge pattern shown in Figure 3; average monthly outputs: 4.6 MW, 1.9 million kWh; 6.5 MW, 2.3 kWh; and 10.6 MW, 3.1 million kWh.

3.1.1 Site Suitability Considerations in Small-Scale Hydro Development

The developer, working with engineers, will generally choose the site that will result in the maximum amount of power for the least investment of money. Of interest to the developer are the rate paid for power, any tax breaks and incentives that municipalities and the Federal government give, the security of water rights, and the financing arrangements available for a particular site. A feasibility study usually is done under a preliminary permit from FERC before in-depth engineering studies or construction work is started. According to Allen (1977), a SSH feasibility study consists of a series of specialized analyses of various aspects of the proposed SSH project, as follows:

- Geology of the site (including seismology);
- Hydrology of the site (including groundwater movement);
- Topography and land use;
- Water uses - existing and competing;
- Reservoir or pondage (if available);
- Analysis of power and energy production for dams of various heights;
- Number, type, and size of generating units needed;
- Power station structure and auxiliaries to serve the generating units;
- Dam and spillway structure;
- Construction requirements and schedules; and
- Environmental constraints and resources present (may require an instream flow analysis to determine probable amount of water available for SSH).

From an engineering viewpoint, the best hydroelectric site normally is the one with the maximum head in the least amount of linear distance. This type of site is comparatively simple to adapt to hydroelectric power generation because only a small amount of land needs to be flooded to obtain a significant head. In fact, most of the best sites for hydroelectric power in the conterminous United States have already been used.

At any site, the total annual power production depends on how much of the available water can be used for hydropower. Requirements for minimum releases of water for environmental purposes and the legal rights of downstream users must be considered in any analysis of site suitability because releases represent a potential loss of gross income from the project and, thus, may affect its economic feasibility.

Perennial streams are preferred for hydro sites because equipment can operate much or all of the year, thus maximizing the return on the investment. SSH is more dependent on natural flow than are larger projects, which can compensate for seasonal fluctuations in flow by using large impoundments. Storage of water at an SSH project is typically minimal, unless the storage is for a use other than hydropower, in which case, the water is typically unavailable for SSH.

The value of a site for a SSH plant also is related to the season in which the maximum discharge occurs. For example, if the plant is to be tied into a regional electricity grid and the electric utility needs most of its output in the summer to meet air conditioning needs, a hydro plant that has its maximum output in the summer will be more useful than one that generates most of its power in the winter. Figure 6 shows the general seasons of maximum and minimum flows in the conterminous United States. The broad regional patterns shown are complicated by local factors, particularly the presence of withdrawals for uses such as irrigation or power plant cooling. The seasonality of flow is determined mainly by climate, but can be affected by storage within the system, either in the ground water, in snow, or in upstream reservoirs. The uptake of water by vegetation and irrigation return flows can be important factors in terms of the seasonality of flows. Headwater streams, which are appealing for SSH projects because they are relatively easy to dam, are especially subject to seasonal flow fluctuations. Lowland streams, which receive contributions from many streams, usually have more predictable and constant flows. However, because of their wide valleys, lowland streams are more expensive to dam and, if dammed, they create a large, shallow impoundment without much head.

A significant consideration for the maintenance of SSH projects (and, therefore, site suitability) is the formation of ice, which clogs screens, damages equipment, and is often associated with floods when it thaws.

3.1.2 Types of Small-Scale Hydro Projects and Their Environmental Impacts

Small-scale hydroelectric installations fall into three broad categories, based on the work required to bring them on-line: restoration; retrofit; and new. Restoration (or rehabilitation) entails bringing a currently unused hydroelectric plant back into service. This process may involve relicensing, rebuilding a breached dam, dredging a reservoir, or digging canals, much as would be required for a new plant; on the other hand, only minor repairs to the existing plant may be needed. The second project type, the retrofit, involves placing hydroelectric generating equipment in an existing dam or other water project structure in order to take advantage of falling water energy that would otherwise be unused for energy production. Fairly limited construction work typically is needed, but temporary cutoffs and diversions of flow are usually required to complete a retrofit. The last type of project, the new project, requires construction of a new dam or diversion structure, a powerhouse, and all necessary auxiliary facilities. Construction for new projects is often extensive, and the essential character of the river at that site is permanently altered as a

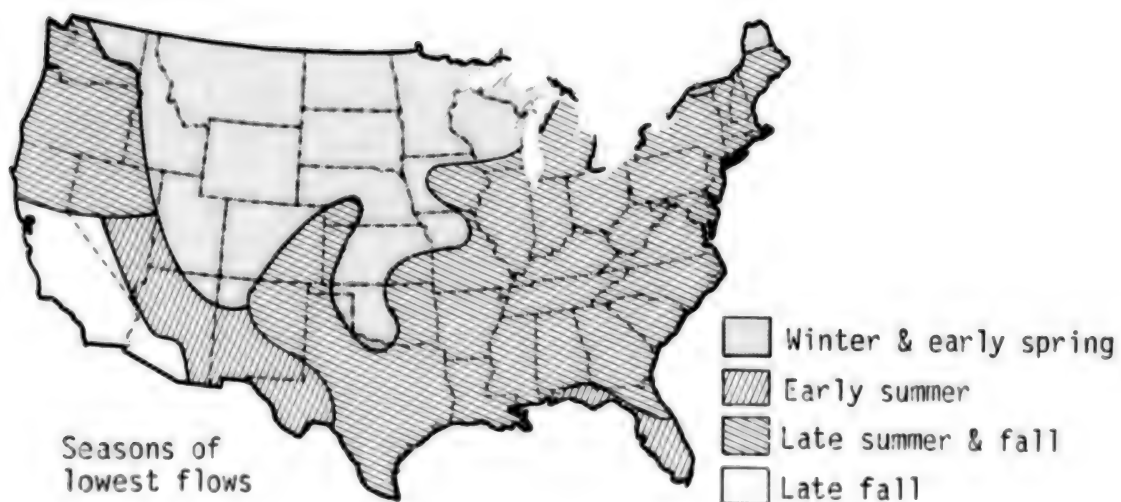
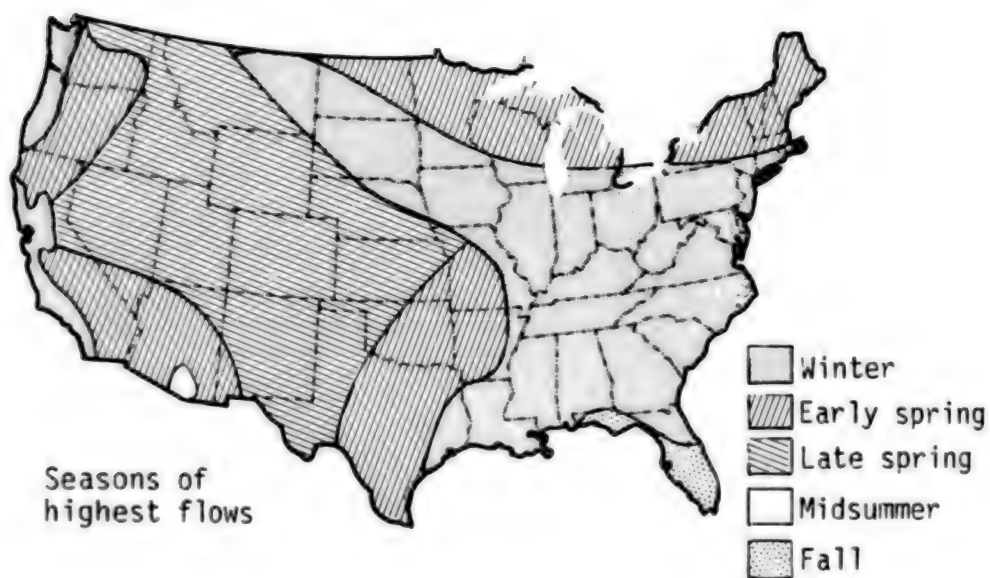


Figure 6. Seasons of highest and lowest stream flows (Langbein and Wells 1955).

result. (Construction activities and their impacts are discussed further in Chapter 4.)

No two SSH projects ever are exactly alike, but projects can be grouped into five general types according to the basic approach used to place turbines in a position to obtain energy from water:

- Conventional hydroelectric plants;
- Multiple-use dams;
- Diversion projects;
- Canal drop systems; and
- Pipe network systems.

a. Conventional hydroelectric plants. The best-known and most common form of hydroelectric plant is the single purpose hydro project (Fig. 7). Most conventional projects that qualify as SSH (<30 MW) are located on tributary streams and are operated with comparatively little water storage; that is, they are run-of-river plants (Section 7.1). However, projects that expand the generating capacity of plants located in the mainstem of some large rivers, such as the Susquehanna in Pennsylvania, are also considered SSH. Many of these expansion projects are operated in the peaking mode (Section 7.2).

The conventional hydro plant depends on nearly complete control of the stream by means of a dam, which spans the entire stream. Conventional, single purpose SSH plants account for more than one-third of the more than 2,000 sites identified by the U.S. Army Corps of Engineers (1981) as having potential for small-scale hydroelectric development.

The best site for a conventional SSH plant has a maximum fall (head) in a minimum horizontal distance, combined with comparatively steady streamflow year-round. The construction involved in preparing such a site for hydroelectric use can be extensive, even if the project is considered a "restoration" project. For example, dam repair can involve anything from minor clean-up and resurfacing to the total rebuilding of an existing¹ dam found to be structurally unsafe or incapable of supporting the additional stress caused by raising the water level of the reservoir. Similarly, modifications to the power house, transmission equipment, or waterways may be major.

¹The term "existing dam," as established in the PURPA legislation, does not mean that a dam is fit for use. Rehabilitation may involve blocking the stream completely, where minimal if any stream obstruction may have existed for decades due to structural deterioration, or total breaching of the existing dam.



Figure 7. View of the Cornell University Fall Creek Hydroelectric Plant, Ithaca, New York (H.M. Brundage). This site has been used for power production since the early 1880s. In 1981 the plant was renovated; two Ossberger cross flow turbines were installed with a total rated capacity of 1.5 MW.

When a plant is established purely for its hydropower potential, year-round flow is desirable because the demand for electrical power is fairly constant in most localities and because a single-purpose project must generate enough income to pay off all the capital costs through the sale of electricity alone. Consequently, small-scale conventional hydroelectric plants are typically found in areas of high annual run-off (Fig. 8). In areas where perennial streams are rare, conventional hydroelectric projects tend to be very large and often are not sole-purpose because impounded water is scarce and also is used for purposes other than power production. The need for a reliable flow accounts for the fact that, of the 2,000 small-scale hydroelectric sites currently in use or under consideration for development, 400 of those classified as pure hydroelectric are in the Northeastern States and 200 are in the Pacific/Western Rocky Mountain States (U.S. Army Corps of Engineers 1981). In contrast, the Southwestern States are estimated to have only six small-scale sites suitable for use solely for hydroelectric power generation; other regions have between 50 and 80 such sites each.

b. Environmental impacts at conventional SSH projects. The areas affected environmentally by a conventional SSH plant include the downstream area, the stream reach above the dam, riparian wetlands and adjacent terrain. Upstream flooding can eliminate terrestrial habitat. It replaces a flowing stream water habitat with an impoundment in which there may be fluctuations in water level. Immediately downstream, instream flow may be reduced or eliminated if water is diverted to a powerhouse located apart from the dam. Further downstream, there may be changes in the physical, chemical, and biological characteristics of the water as a result of flow regulation that may influence the capacity of the stream to support life.

A dam that blocks a stream invariably affects the movement of fish. SSH projects provide an opportunity to improve fish movement when added at the site of historical dams at natural falls where upstream fish passage does not occur. However, where there are a series of low dams in rivers where there were historic fish runs, such as the Schuylkill River in Pennsylvania, the dams must be retrofitted with upstream and downstream passage facilities if fish runs are to be restored.

Perennial streams are often exploited at several places along their length, because the water used at one run-of-river project can be continuously released and made available for downstream plants. This often results in cumulative impacts, such as nitrogen supersaturation, fish mortality in turbines or spillways and habitat destruction. Extensive development of perennial streams is more commonly planned and encountered in the Northeast and Pacific Northwest States, which are both important anadromous fish areas. This exploitation of streams by SSH projects may be in direct conflict with the maintenance or improvement of fishery resources.

The environmental impacts of transmission lines include the direct impacts on raptors, including threatened and endangered species. Indirect problems may be created by increased visitor access due to new roads. This

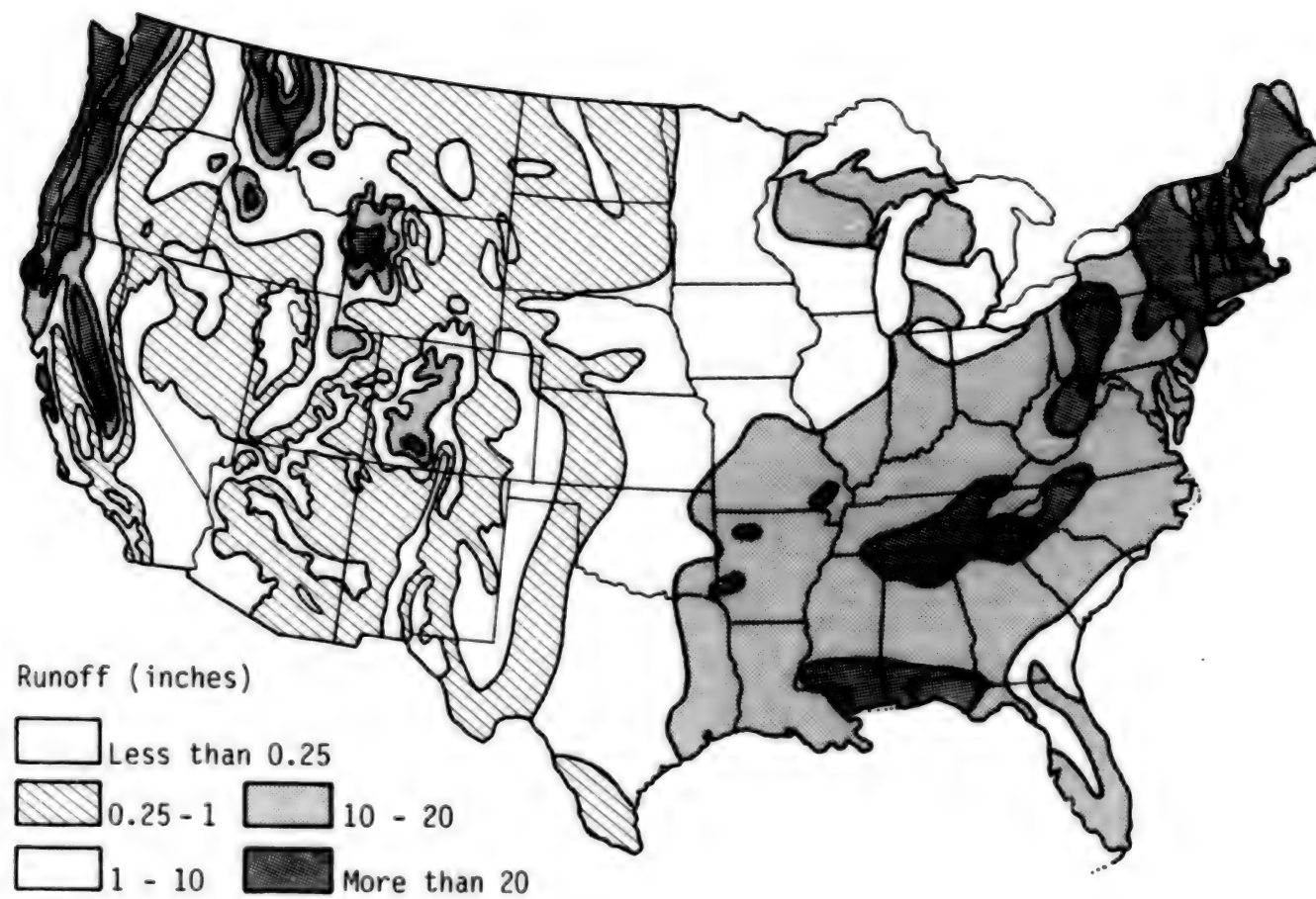


Figure 8. Average annual runoff in the United States (Dunne and Leopold 1978).

increased access may result in unregulated fishing and hunting, the disturbance of bird nests and mating grounds, and fires. Allowing off-road vehicles into remote sites may result in the destruction of cover, increased soil erosion, and the pollution of streams with silt. Impacts associated with opening up remote areas are a particular problem in the Pacific/Rocky Mountain, Southwest, and Alaskan regions.

c. Multiple use dams adapted for hydroelectric use. Hundreds of existing dams of various sizes throughout the Nation could be retrofitted to produce electric power. Such dams were originally built to control or store water for such purposes as municipal water supply, flood control, recreation or wildlife management, industrial water supply, agricultural use, or for a combination of these uses. Table 3 shows the number of dams with hydroelectric potential that currently have nonhydroelectric uses, according to a recent feasibility study (U.S. Army Corps of Engineers 1981).

The important consideration when SSH is applied to multiple-use dams is that the pattern of water flow is governed by the original use in virtually every case and will probably continue to be operated in such a manner. For example, if the releases from a dam are timed to provide flood protection, they usually will continue to be released in this pattern after SSH is added.

Most dams designed for water storage are higher than dams designed for other purposes (e.g., navigation or sole-purpose hydroelectric). However, the dam height may be increased to increase power potential during the adaptation of the dam to hydro use or other construction work may be required. These activities generally are limited by the engineering constraints of the original dam and the likelihood that major structural alterations will not be very great.

Lock and dam structures, such as those found on the Ohio, Allegheny, and Monongahela Rivers, are a type of multiple-use project that is well suited to SSH retrofit. At least one manufacturer is working on the concept of a replacement gate with a turbine built inside it. With this device, construction activity and the resulting environmental disturbance will be minimized.

When a multiple-use dam is retrofitted with hydroelectric equipment, the preexisting effects may be exacerbated by the SSH project and must be considered in the licensing process. Changes in flow are likely to be slight, because only water that is not already committed to the preexisting use can be used for SSH. However, the character of the releases may change. For example, in a flood control project, water in the reservoir may have been allowed to fill until spillage was achieved. With SSH in place, spillage may not occur because the water is diverted through the turbines as fast as it fills the reservoir. With reduced spillage, there may be less of a problem with nitrogen supersaturation (which can cause gas bubble disease in fish), but an increased potential for turbine mortality. A retrofit project on a nonhydropower dam may create a

Table 3. Number of active nonhydroelectric dams with potential for SSH power (U.S. Army Corps of Engineers 1981).

Original project purpose	U.S. Fish and Wildlife Service Region ^a							Total
	1	2	3	4	5	6	7	
Flood control	7	1	2	4	12	2	0	28
Irrigation	21	0	0	0	0	15	0	36
Recreation	2	1	15	4	18	5	0	45
Navigation	0	0	2	44	30	0	0	76
Water Supply	6	11	2	3	35	6	0	63
Other ^b	15	2	3	12	280	8	1	321
Multiple use	<u>183</u>	<u>133</u>	<u>78</u>	<u>123</u>	<u>90</u>	<u>71</u>	<u>5</u>	<u>683</u>
Total nonhydropower	234	148	102	190	465	107	6	1,252

^aRegion 1: Washington, Oregon, California, Idaho, and Nevada.

Region 2: Arizona, New Mexico, Texas, and Oklahoma.

Region 3: Minnesota, Wisconsin, Michigan, Illinois, Indiana, and Ohio.

Region 4: Arkansas, Louisiana, Mississippi, Alabama, Tennessee, Kentucky, N. Carolina, S. Carolina, Georgia, and Florida.

Region 5: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, and West Virginia.

Region 6: Montana, Wyoming, Utah, Colorado, North Dakota, South Dakota, Nebraska, Kansas, Iowa, and Missouri.

Region 7: Alaska

^bOther purposes include farm ponds, debris control dams, miscellaneous types not indicated in the source, and dams of unidentified purpose.

dewatered zone below the dam that did not exist before. Adding hydropower to an existing project has the potential to permanently institutionalize a condition that is destructive to fish and wildlife habitat and population.

A recently completed 4.75 MW project at the Ashokan Reservoir near Kingston, New York, is a multiple-use project using the New York City water supply to generate power (Faber 1982). It illustrates the complexity of some SSH concepts in that its upstream portion is a small reservoir, but the discharge is directly into the Catskill Aqueduct, making it a hybrid between the multiple-use projects described in this section and the pipe network system described below.

There have been some reports of dissolved oxygen problems related to hydro additions to lock and dam projects. Typically, the gates at a lock and dam structure are placed at or near the surface so that deeper, poor quality (O_2 depleted) water is retained in the impoundment. However, some navigation impoundments are retrofitted for hydro by installing intakes in deep water to maximize the head. This means that water from the deepest layers of the upstream side, which may be low in dissolved oxygen and contain accumulated sediment and pollutants, is discharged on the downstream side, creating a local problem of low dissolved oxygen. Counterbalancing this, to some extent, is the fact that the system provides considerable aeration to the water because an artificial jump structure is typically present downstream of the gate to disperse the energy of the water passing through.

Of course, adding turbines to a lock and dam to take advantage of spilled water means that, when the project is operational, water that formerly flowed freely through open gates will be passed through turbines, resulting in potential turbine mortality to downstream-migrating and resident fish (see Chapter 6 for further discussion.)

d. Diversion projects. Some SSH projects are designed to remove water from the natural stream bed, divert it into a penstock (pipe) or canal, pass it through a powerhouse at a lower elevation, and release the discharge back to the stream or, sometimes, into an entirely different drainage basin. A conventional dam and penstock may completely dewater a stream for substantial distances by diverting the entire flow of a stream (except during floods). In some projects, the stream is not totally blocked, as shown in Figure 9. The extent of the diversion varies with the need for continuing adequate stream flows. Diversions are best suited for sites with a steep gradient and steady flow, at least during the season in which power is desired.

A variation on the stream diversion concept is the lake tap. In this type of project, a tunnel is drilled into a natural lake, which may or may not have its elevation raised slightly by a small dam. The downstream end of the tunnel is connected to a penstock that leads to a powerhouse far enough downstream to generate a useful head. Lake taps can generate comparatively large outputs; for example, Tyee Lake (20 MW), Green Lake (16.5 MW), and Terror Lake (20 MW) in Alaska.

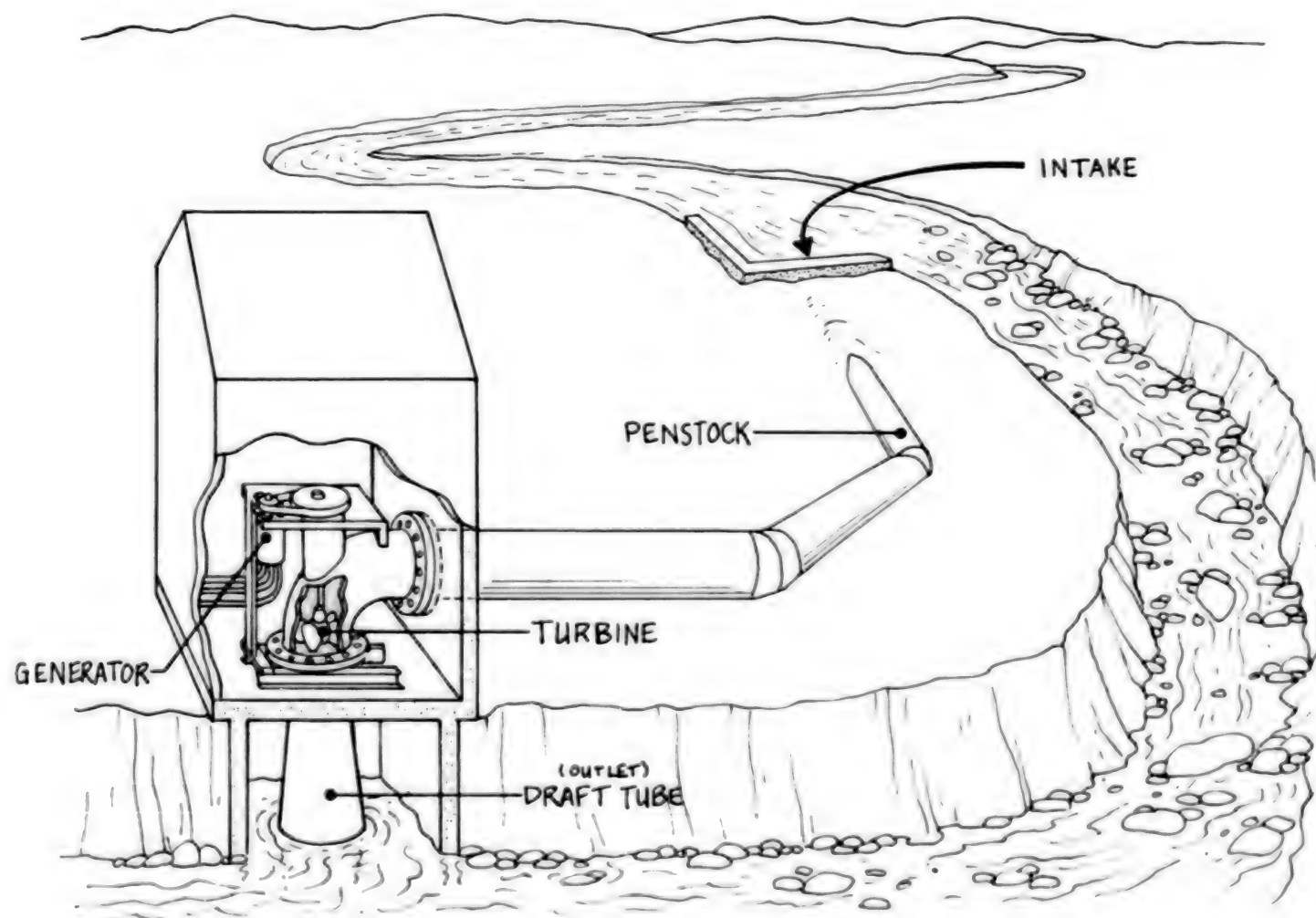


Figure 9. Small-scale hydro plant using a diversion (Alward et al. 1979).

Diversions also can be installed on streams for a number of reasons other than hydropower, particularly in water-short areas where water from one river or canal is diverted into another. Many of these existing diversions could be exploited for SSH, either in the diversion structure or pipeline or in the diversion dam itself. A SSH project may be installed in the spillway portion, thus using only water not needed for other uses.

The variations among diversion projects are potentially great. Some small diversions may be used only seasonally or as emergency or supplemental power. As with other multiple-use systems, when SSH is added to an existing diversion, its operations are governed by the original use.

Little information is available regarding the number of diversion projects proposed throughout the Nation. Many small and large diversions are proposed in the Western States. Many that were considered unfeasible in the U.S. Army Corps of Engineers' (1981) study may be developed by individuals to meet their particular needs. At many marginal sites, the effectiveness of existing SSH has been, or could be, enhanced by interbasin transfers of water. In the Eastern States, there are diversions involving old industrial mill races where a canal was built to capture part of the stream flow for water power, water supply, or cooling. Such projects typically have a dam at the head-water end, a canal approximately parallel to the river axis but at much less slope, and an outlet structure at the mill that discharges back into the main stream. There are hundreds of such sites in New England in varying degrees of disrepair and decay; many of these sites could be restored for SSH use.

Diversions vary in their impacts depending on whether or not they have a complete dam at the point of diversion and on when and how much of the flow is diverted (Fig. 10). Failure to provide the needed instream flows causes the greatest and most frequent impact. In some cases, the biological productivity of the diverted stream reach can be totally eliminated unless maintenance flows are specified and provided. If the load of sediment and debris is forced to move along the main channel while "clean" water is diverted, changes in stream depth and habitat character in the original channel will occur. If diverted water is returned to a drainage basin different from the one from which it was obtained, both the donating and receiving drainage areas will have altered streamflows and sediment loads. This can be manifested by changes in stream bottom characteristics, channel morphology, bank erosion, flood frequencies, and ground water storage.

Diversion of water by a partial dam may create a narrow reach of extremely high flow. If fish cannot pass this point the blockage may be as effective as if a complete dam were present, unless fish passage facilities are provided.

3.1.3 Canal Drop Systems

Canals and aqueducts move water for irrigation, potable water supply or navigation. Many canal systems include a series of dams which offer an opportunity for SSH. Between dams, water depth increases gradually so as

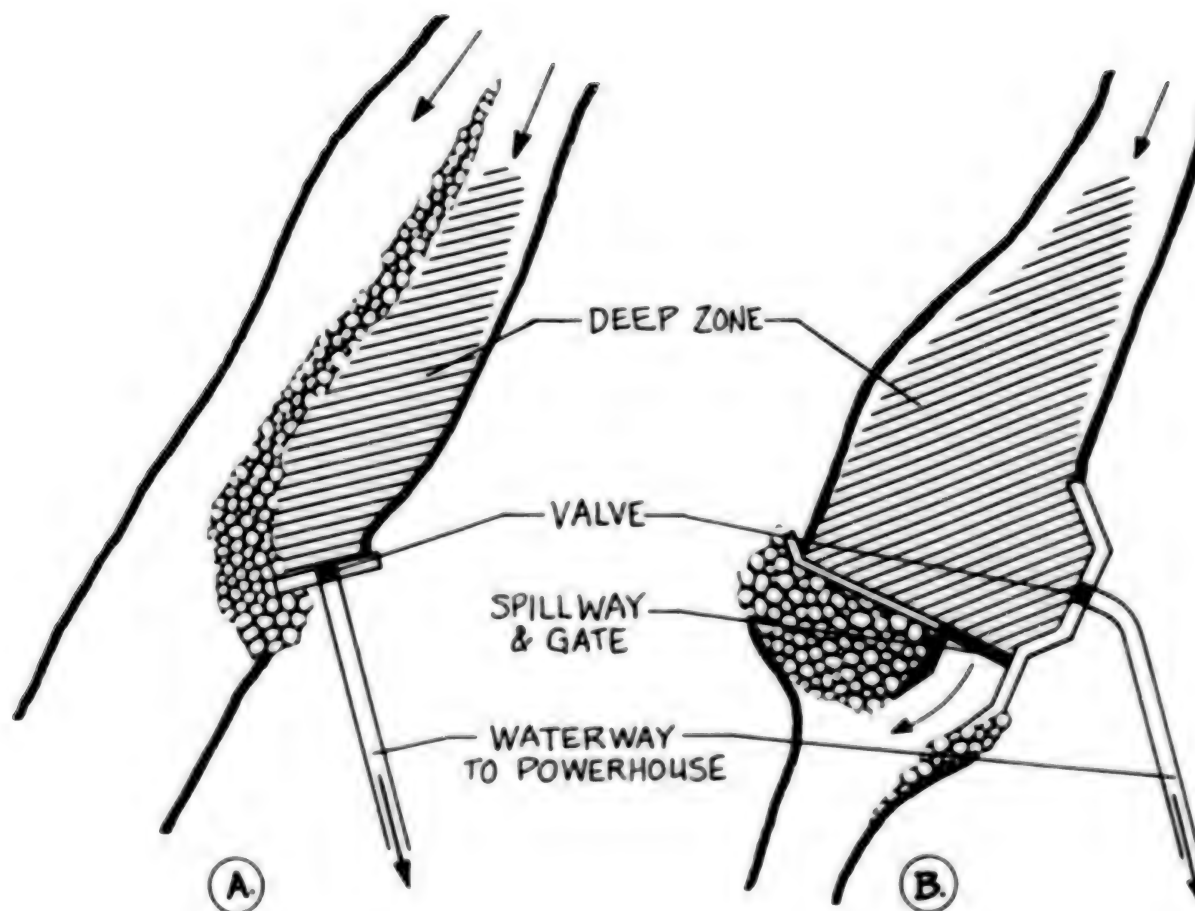


Figure 10. Diversion designs and their effects on streamflow (T. Lloyd Associates). A. Partial diversion; B. Dam, with spillway and gate.

to maintain flow. When it reaches the next dam, there is an abrupt drop in elevation to the head of the next canal reach. Numerous proposals and plans have been advanced to generate electricity using water spilled at these dams. Off-channel storage dams designed to maintain flows in the canals also provide an opportunity for SSH.

Most of the irrigation and potable water supply canal systems are in California and other Southwestern States. SSH is especially compatible with irrigation systems because water flows are highly regulated so that power generation can be sized according to the site. SSH facilities need not be designed to operate over a wide range of conditions, thus reducing costs. Frequently the turbine can be installed in an existing weir or gate.

Other types of canals can be developed for SSH. Many small navigation canals once existed in the Middle Atlantic States and New England. Most of these are badly deteriorated; however, short segments of some canals may be useful for SSH. New England also has hundreds of mills, built in the seventeenth and eighteenth centuries, which relied on water for mechanical or electrical power. Many of these sites could be restored and operated like the single purpose SSH plants previously described when SSH facilities are added to irrigation and water supply systems. At such sites, impacts tend to be additions to or variations on existing impacts, because, as in the case of multiple-use dams, water releases in the system are predetermined.

The absence of freeflowing stream reaches in an area means that warm water fish species, if any, are likely to be present and that any biotic communities remaining are those adapted to the existing conditions. Addition of SSH probably would not affect the fundamental character of such sites.

Negative consequences resulting from adding SSH to a canal may occur, however. For a canal to function successfully, it must be balanced in terms of water supply, sediment load, and slope. If the hydro plant removes a significant amount of energy from the flowing water, it may upset the sediment regime, resulting in increased siltation in the canal that will ultimately reduce flow. Dredging to correct this problem would likely result in turbidity, downstream siltation and possibly spoil disposal problems. A reduction in flow and water depth might encourage the growth of aquatic weeds, which would, in turn, lead to possible dissolved oxygen and organic load problems in the canal in addition to weed control problems. The entrance of fish into the canal system constitutes a loss to the population above the diversion, and possibly a total loss if conditions in the canal are not suitable for survival.

Little is known about the specific environmental effects of adding SSH to canals because so few of them have been in operation for any significant period of time. There are large numbers of proposed projects, particularly in California. If they should all be approved and built, significant cumulative effects could result that cannot now be anticipated. It is

possible that water quality could be affected to the detriment of its intended use (irrigation or human consumption), necessitating costly corrective measures. Construction impacts at canal sites in the Southwest may also be significant because the vegetation is slow to replace itself after disturbance by vehicles and grading of soil surfaces.

a. "In-conduit" or pipe network systems. Water supply, wastewater systems and other conduit facilities such as at hatcheries offer potential for SSH development. Often there is excess pressure in such a system, which is being dissipated by pressure-reduction valves, or the system will end in a drop, which represents unutilized head. The Metropolitan Water District of Southern California has proposed several SSH projects in which turbine generators are placed in large diameter tunnels or small conduits at various places within Metropolitan's water distribution network. Most of the proposed projects would be in highly urbanized areas along city streets, with most of the equipment, including the powerhouse, underground (Fig. 11). Many of the transmission lines may be at least partially underground and connected directly to existing transmission lines. Projects involving sewer outfalls have been proposed for Chicago and North Carolina. In these cases, the turbine would be placed in the actual outfall to take advantage of the drop between the lowest point in the plant and the elevation of the water body that ultimately receives the treated waste. FERC has special regulations regarding exemptions for "in-conduit" projects up to 15 MW in size.

Flows within conduits are governed by the original purpose of the system, whether it is water distribution or waste removal. As a result, operation is in a "run-of-river" mode. The comparative predictability of flows makes it possible to use pumps as turbines and, in some cases, substantially reduce the costs of installation.

Conduit networks of significant size and head are primarily found in urban areas, although irrigation systems also offer potential for this type of development. There are substantial urban areas in all regions that could theoretically exploit this power source. The principal requirements are excess head in the system and the suitability of the pipe system for modification; these conditions vary depending on the local situation.

Because conduit networks are usually enclosed, direct environmental impacts are minimal, except during construction when extensive digging may be required. The nature of the construction is similar to that commonly in progress throughout urban areas.

Because the proposed projects are in different stages of design and installation, there is little environmental record to draw upon. Indirect impacts could result from changes in flow rate or in water quality due to turbine operation. However, such impacts are difficult to separate from the primary impacts of the water supply or waste disposal system to which SSH is added. We do, however, have experience with economic dependence on hydropower that is hinged to consumptive water use practices, such as for irrigation. This, in turn, reduces water availability for fish and wildlife purposes and can impact water quality adversely.

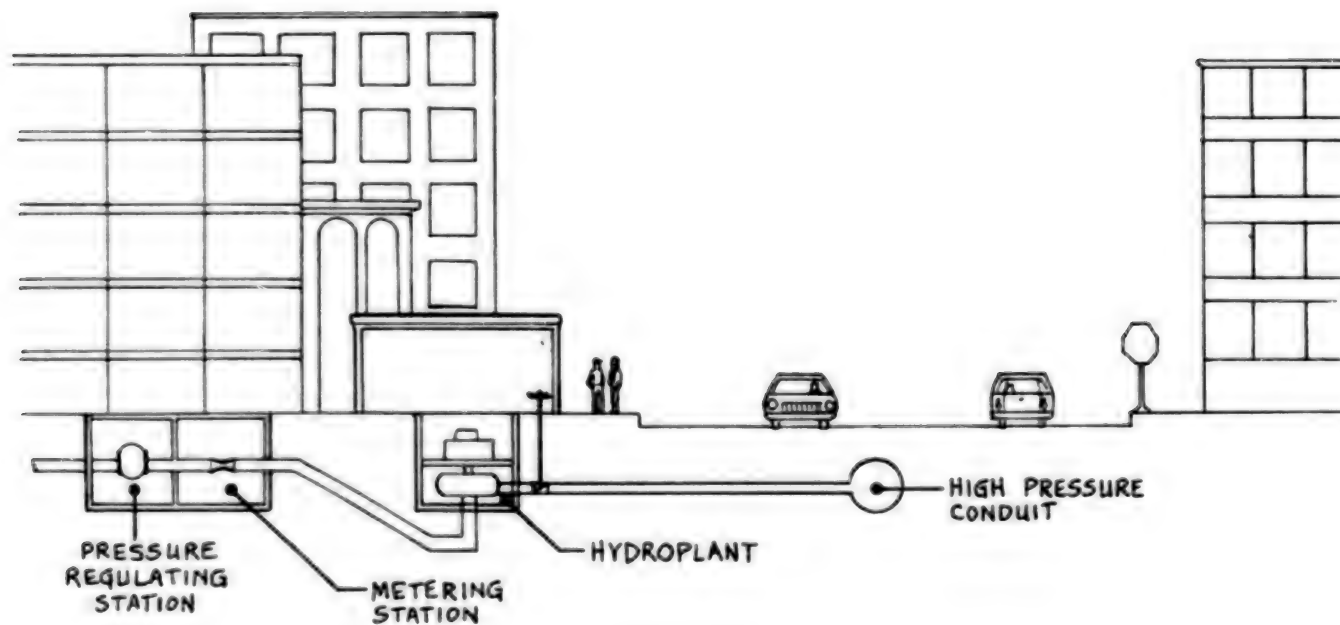


Figure 11. An urban small-scale hydro plant designed to use an existing pipe network (MacDonald and King 1981).

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4. CONSTRUCTION-RELATED IMPACTS

Many activities occur during the course of construction, even at a comparatively small SSH project (Fig. 12). Impacts from several construction activities often occur simultaneously. The duration of any given impact is difficult to predict; it depends on the duration of the related construction activity and the recovery time of the affected portion of the ecosystem. The duration of the resulting impacts is related to their magnitude, the components of the ecosystem involved, and the response of the ecosystem to mitigation.

The following sections discuss preconstruction and construction activities and their likely environmental effects. Not all of these impacts would occur at any individual SSH project because specific construction activities vary from site to site according to local conditions and needs.

4.1 PRECONSTRUCTION ACTIVITIES

4.1.1 Description

Preconstruction activities focus on the collection and analysis of the environmental, engineering, and economic data necessary to determine project feasibility and to draw up project plans. Generally the planning process involves at least three phases: an initial (reconnaissance) phase in which three or more potential projects may be considered in light of the developer's limitations and objectives; a second phase, which usually amounts to a feasibility study of one or two projects; and the third phase, in which detailed site investigations are begun. For some projects, the site is predetermined because it is the only one the developer is interested in, such as when a municipality wishes to rehabilitate an abandoned city facility. In such a case, only the third phase of preconstruction activities is necessary.

Most feasibility studies include (or should include) preliminary environmental assessments. This reconnaissance assessment should quickly identify the major ecological constraints. The instream flow analysis is typically required of projects in Alaska and the Western States early in the project to determine how much water is available. Disturbance to the site usually occurs first during the second phase, the feasibility study, when sufficiently precise information to permit an estimate of project costs is sought. This, and the later detailed site survey, require intensive on-site investigations, with resulting disturbance to the site. The

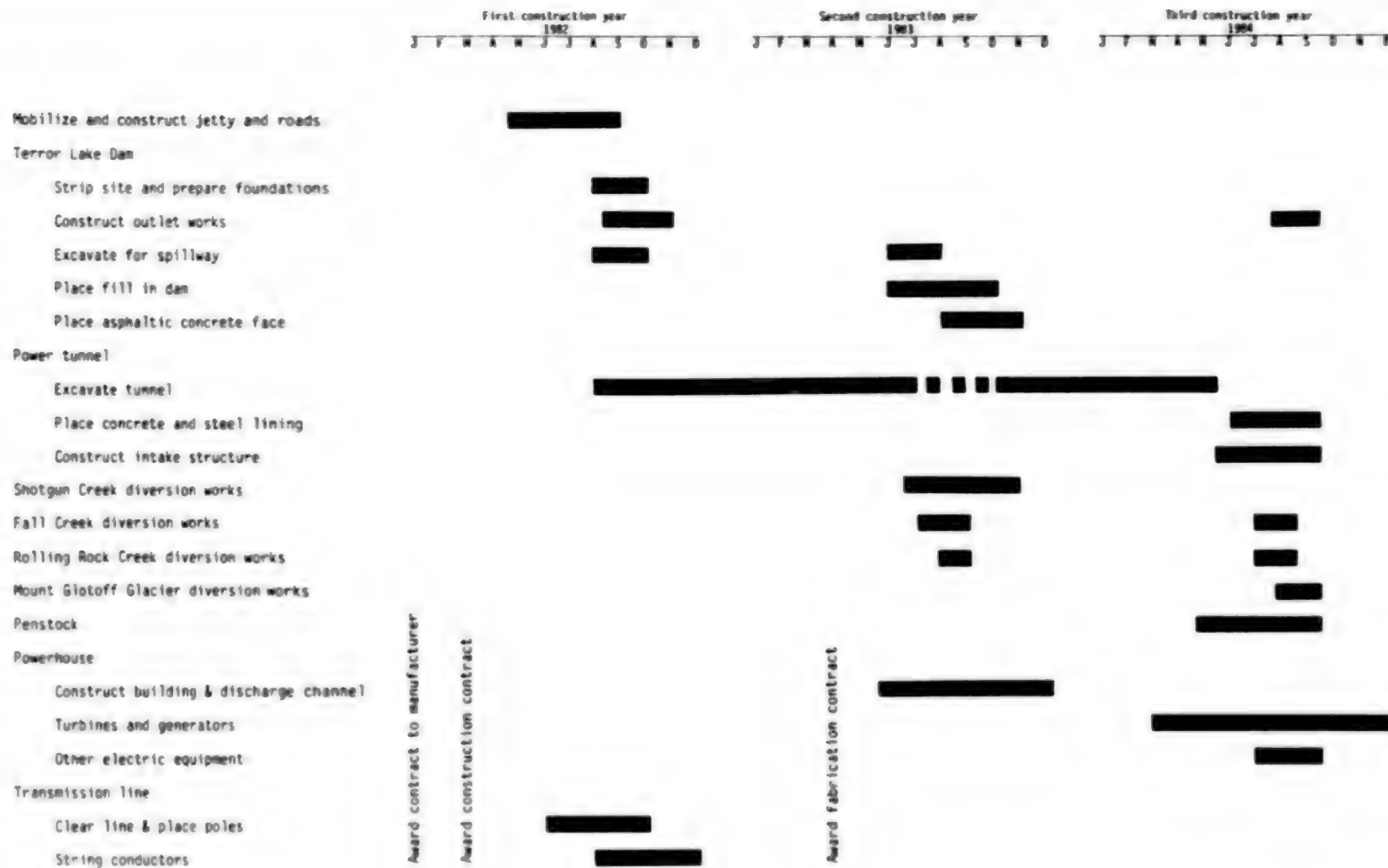


Figure 12. Construction schedule for Terror Lake, Alaska, a 20 MW lake tap plant (U.S. Department of Energy, Federal Energy Regulatory Commission 1981).

tasks of the engineers, geologists, surveyors, and other specialists include:

- Inspecting any existing facilities (such as dams, waterways, and turbines) to determine their future usefulness;
- Conducting soil, geological and geotechnical investigations to ensure the proper design and protection of a new dam;
- Performing hydrologic studies to determine the availability of water for hydropower and to ensure the proper design of the dam, spillway, and other structures;
- Locating the boundaries of the area to be flooded, the rights-of-way for transmission lines, and sources of suitable construction materials (sand and gravel);
- Formulating plans to relocate public utilities and roads that would become unusable with the project in place, for access roads and storage areas for building supplies and construction equipment, and (if necessary) for housing for transferring construction workers;
- Finalizing project design and implementation plans;
- Obtaining sufficient environmental data to license the project;
- Obtaining necessary local, State, and Federal permits; and
- Holding public hearings and participation.

It may be necessary to construct access roads for drilling and other heavy equipment. This could result in both primary (such as vegetation removal, erosion and siltation, and noise disturbance) and secondary impacts, due to increased public access.

Other activities that are likely to occur prior to project construction include temporary drawdowns of the impoundment of an existing facility to inspect the dam or appurtenant structures, seismographic studies to measure the depth to bedrock and its characteristics, removal of vegetation by survey crews, and the construction of temporary storage or stockpiling areas.

4.1.2 Engineering and Economic Considerations and Trade-offs

The type of SSH project and the on-site conditions are important factors that determine the nature of field investigations. Relatively little effort is usually necessary to prepare for a diversion dam, as compared to a high earth or concrete dam. Similarly, if the soils underlying the area where the dam will be located are deep and variable in texture or if the

bedrock is fractured or unstable, detailed studies should be carried out (see Section 5.1, Dams and Impoundments).

Planning studies are an expense that is borne by the developer until the entire project is completed and begins to generate electricity. Therefore, the details of preconstruction planning studies may be determined in part by the financial constraints of the developer and the potential payoff for the project. For example, an engineer may base subsurface investigations on seismic tests in order to minimize drilling costs. Seismic tests may be sufficient to determine the depth of the overburden and the general characteristics of the underlying bedrock, but provide little information on texture and other soil properties, which only can be obtained from a core sample. The trade-off here is whether or not the additional information that could be obtained from core samples ultimately would pay off in terms of more appropriate project design or in the safety analyses required for licensing.

4.1.3 Environmental Effects, Trade-offs, and Mitigation

The environmental impacts resulting from preconstruction activities generally are not severe. The new access roads, with a related increase in erosion and sedimentation, noise, and human encroachment, are a potential environmental impact of this project phase.

There may be environmental benefits associated with proper planning and scheduling of construction activities. For example, it may be possible to avoid the reproductive or migratory activities of certain animals by careful timing of construction activities. However, these benefits must be balanced against any possible negative impacts. For instance, scheduling the construction action to avoid migration may mean that construction occurs in a period when there is increased erosion.

Efforts to mitigate the adverse effects of preconstruction activities consist mainly of limiting access to critical areas, properly siting road and bridge locations and controlling erosion.

4.2 CONSTRUCTION ACTIVITIES

4.2.1 Description

Once construction begins, several activities may be occurring simultaneously on a given site (Fig. 12). The usual order of these activities is listed below. Not all these steps will occur on all SSH projects, and the order may be different on some projects. These activities can be grouped in three categories, as follows:

Preparation Phase

- Opening and preparing access roads and storage sites for materials and equipment, including preparing for drainage, clearing peripheral vegetation, and controlling dust.

- Delivering and rigging equipment (e.g. derricks, cement plants, rock crushers, worker and office trailers, and temporary buildings).
- Constructing temporary electric lines, water supply, and waste disposal facilities.
- Opening small landfills.

Site Modification Phase

- Dredging or flushing existing reservoir.
- Draining reservoir to expose dam.
- Tunneling through rock to provide waterway to powerhouse.
- Constructing cofferdams and diversion channels (Figure 13).
- Dewatering part of the stream near the dam site.
- Demolishing all or part of existing dam, levees, bridges, and other structures unfit for use in the SSH project.
- Filling and/or bulkheading stream or reservoir shoreline to provide more flat land for structures and roads.
- Channelizing parts of stream and building or rebuilding canals.
- Scraping and shaping exposed reservoir and canal bottoms, including removing trees, stumps, and other large objects.
- Clearing (killing) vegetation along shorelines, transmission line rights-of-way, building sites, parking lots, boat ramps, and other areas.
- Blasting and/or excavating to remove obstructions or to deepen footing and foundation areas and to prepare road cuts.
- Burning or disposing (either on-site or off-site) of vegetation debris, demolition waste, oil, tires, dredge spoils, and topsoil.
- Grading and rough surfacing roads and parking areas.

Construction Phase

- Obtaining materials off-site, including opening borrow pits or mines, possibly not in the same drainage basin as the SSH project.



Figure 13. View of the small scale hydroelectric retrofit project located in the Hoosic River, Upper Mechanicsville, New York (New York State Electric and Gas Corporation, Binghamton, New York). The cofferdam at the lower left of the picture was used to dewater the area occupied by the old intake works. The housing for two turbines can be seen to the left of the crane. The new tailrace is located in the area occupied by the siltation basin.

- Building or rebuilding dams, spillways, intakes, and diversion structures, including resurfacing the dam, grouting, and completing demolition and excavation (such as removing cofferdams, and temporary stormwater detention basins).
- Building waterways, canals, and penstocks.
- Installing flow control devices (gates and screens) and fish passage devices.
- Erecting transmission towers (involving use of heavy equipment on natural vegetation cover), minor excavation and concrete work, and removing tall trees outside actual right-of-way.
- Building powerhouse support facilities, such as visitors' areas, septic tank or water treatment plant, permanent lighting, permanent fencing, and parking areas.
- Building switch yards and transmission facilities, including fencing gravel yard, and concrete foundations for transformers and towers.

It is necessary to know what work will be done before construction-related impacts can be predicted accurately, but details of planned construction are not always obvious from a permit application. A simple statement about the "delivery of equipment to site" may imply several other activities not mentioned, such as building an adequate road, cutting down trees, fording minor streams with heavy vehicles, storing of fuel and oily waste, and fencing the project area. Also, suitable fill must be obtained somewhere if there is to be an earthen dam, so even if the developer does not describe earth moving and transportation, it may be assumed that these activities will take place. The next several paragraphs include additional details on the construction activities most likely related to environmental concerns.

a. Stripping vegetation. Vegetation, often including its associated topsoil, is removed to make way for equipment yards, building sites, and access roads. Vegetation is stripped from the shoreline and impoundment bottom, in many cases, to reduce possible hazards to recreational users. Pathways of conduits and transmission lines are usually stripped of vegetation, either mechanically or chemically, using herbicide spraying. Corridors sometimes are replanted with a cover crop. Vegetation removal also occurs off-site at borrow pits.

b. Dredging and landfilling. Dredging refers to excavation under water. It may be done by shovel or dragline equipment or by hydraulic equipment. Dredging is commonly used in the restoration of abandoned hydro facilities to increase pondage (i.e., storage capacity), clear the way to intakes, deepen canals, or clear channels in the tailwater or head of reservoir areas. It necessarily includes spoil disposal, which may occur

elsewhere in the basin or channel or on land, either near the reservoir or at a remote site.

c. Dewatering and flow diversion. It is necessary to dewater the immediate area of the dam site very early in the process of dam construction or rehabilitation. This is typically accomplished by building a cofferdam (a temporary earth-filled dam) and a diversion canal or pipeline to move the water around the dam site. The dewatered period usually lasts until the dam is completed or the turbine equipment is installed.

d. Channelization. Stream channels are often permanently modified to better fit the needs of the SSH project. This may involve channel straightening, removing natural sediments, increasing gradients by removing natural bends, and raising the banks high enough to isolate the floodplain from natural overflows.

e. Excavation. Excavation is done for the footings and foundations of dams, buildings, and transmission towers, to establish a gradient along penstocks or canals, to construct remote spillways, and to obtain fill for dam construction. Excavation is normally part of road construction and may be necessary to provide space for buildings in narrow valleys. Excavation may involve blasting when bedrock is near the surface.

f. Demolition. When restoring SSH facilities, there is often a need for the destruction and removal of older structures no longer sufficiently useful or safe to be included in the new system. This may include dams of rock-crib or stone-wall construction, masonry or stone buildings, canal walls and locks, jetties and docks, and old factory or railroad bed areas frequently found along rivers. Demolition usually requires heavy equipment, both for wrecking the structures and for carrying away waste and disposing of it off site. Masonry structures usually yield a great deal of dust when demolished.

g. Vehicular traffic. Every SSH construction project necessarily increases vehicular traffic, both on the site and to and from the site. Depending on the size and remoteness of the project, some workers may live temporarily (weeks or months) at the site. Otherwise, most traffic reaches the site by trucks and other vehicles, including barges or even helicopters. Traffic volume is typically low during the preparation phase and peaks during the construction phase, when the maximum number of workers and pieces of equipment are on site.

h. Off-site construction activities. Off-site activities that may result in environmental impacts include quarrying or excavating to provide fill for dam construction, dumping wastes from demolition and excavation, trucking, and building the transmission lines. In the Eastern United States, most hydro sites are within a few kilometers of a grid interconnection. However, lines may be much longer in the West and in Alaska. For example, at Terror Lake on Kodiak Island, Alaska, a lake 6.4 km long and about 1 km wide has been planned. The accompanying transmission line is projected to be approximately 27.7 km long. The land area involved in the

construction of the transmission line is about 50% of that of the reservoir, thereby adding significantly to the total area affected by the project.

Construction activities occurring at the SSH plant site can result in off-site effects, such as downstream sedimentation, short term instream flow decreases or increases, and temporary thermal and chemical pollution.

i. Rehabilitation versus new construction. There are numerous small hydropower plants in various stages of deterioration throughout the country, especially in the East. Some of these facilities may have been used for electric power production, others only for hydromechanical mills or pumps. Some sites still have dams, but the dam has collapsed or washed away in many cases, reopening the stream to fish migration. Restoring the dam without suitable fish passage measures could close the stream channel to migrating fish. Fig. 14 shows a breached hydroelectric dam, on the lower Saranac River, in Clinton County, New York. There is a proposal to reconstruct the dam and install new turbines.

Rehabilitating old hydropower facilities requires many of the same steps that are taken in new projects; the distinction between "new" and "rehabilitation" project is not a very useful indication of the extent of environmental impacts. Installing a small turbine in an operating navigation lock is, technically, a new project. However, rebuilding or repairing a dam across a major waterway, such as the Connecticut, Susquehanna, or Potomac Rivers, would probably have a greater effect on fish and wildlife. This type of rehabilitation project might even involve the loss of habitat, most likely a wetland, that had developed because the old dam breached or because a neglected reservoir filled with sediment and vegetation.

4.2.2 Engineering and Economic Considerations and Trade-offs

Most planning and construction steps are quite specific and necessary for completion of SSH projects; they appear in standard handbooks (Creager and Justin 1950; U.S. Army Corps of Engineers 1979).

Seasonal factors will influence the construction schedule. Particularly important are frozen ground, flood flows and adverse weather. For example, if it becomes too cold for concrete to set properly, related activities may stop also, because construction steps typically are closely interdependent. Changes in construction plans may also result from so-called "hidden conditions", which become apparent only after construction begins, despite extensive preconstruction studies. More demolition, more excavation, or increased blasting may be required unexpectedly late in the construction phase. This supports the advisability of having environmental scientists involved in the project throughout the construction phase to avoid adverse impacts related to altered plans and schedules.

The main economic concern during the construction phase is the schedule, which must be met if the project is to remain within its overall budget. Cost overruns, caused by "hidden conditions", construction delays,



Figure 14. View of a breached dam on the Saranac River, New York (New York State Department of Environmental Conservation). A proposal is being reviewed to reconstruct this dam as part of a hydroelectric project.

rental fees for idle equipment, and inflationary increases in labor and material charges often become significant if the delay is a long one.

Trade-offs in engineering and economic areas are closely intertwined during the construction or rehabilitation phase of project development. For example, a turbine manufactured by one company may be more expensive, but have a more dependable delivery schedule than a turbine from a second company. Cost savings resulting from timely delivery could make the more expensive model the best choice.

In the urbanized areas of the East, where most rehabilitation projects are likely to occur, the diversity of hydro opportunities, interest groups, and related industries near the hydro site may result in great project complexity. The more complex a project is, the more likely it is that project schedules cannot be kept, making original objectives for the timing of construction activities in order to reduce the impacts on fish and wildlife difficult to meet.

4.2.3 Environmental Effects, Trade-offs, and Mitigation

a. Physical effects. Changes in stream flow regime, increased turbidity, and increased siltation are often the most significant construction-related impacts of SSH projects. Large changes in stream flow and water quality may occur during construction. When water is diverted or blocked, a dewatered zone may be created. The severity of the impact of dewatering depends on the nature and extent of the diversion and the existence of ground water flow into the area, but it may result in stranded fish and the destruction of wetland habitats. Roads, causeways, and filled areas, if not properly culverted, can obstruct the flow of water from small feeder streams and wetlands, effectively blocking their contributions to the larger stream and creating pools of stagnant water.

Sediments are contributed to the waterway through dredging and the disposal of dredge spoils, by demolition waste, and as a result of excavation. Vehicles may compact soils and destroy vegetation cover. The repeated passage of heavy vehicles results in a smooth surface with reduced porosity and resistance to water, which increases stormwater runoff rates and can cause gully erosion. Thus, turbidity and downstream siltation tend to increase as large areas are denuded of vegetation and as diverted waters or increased runoff erode otherwise stable surfaces. The sediments ultimately settle out, reducing channel capacity in streams.

b. Chemical effects. There is little direct chemical impact due to construction per se. Air pollutants may be released from equipment, from burning waste and from dirt on roads. Clearing rights-of-way for transmission lines and roads may involve both herbicide spraying and waste burning. The immediate effect is air contamination, often followed later by the washing of these materials into streams.

Changes in water quality caused by substances absorbed on sediments and washed into streams may have significant effects. Phosphorus, heavy

metals, and pesticides plus other toxic materials may enter surface water in this manner; these substances can affect all levels of the aquatic food chain.

Wash water from concrete mixers contains very fine particulates that are highly alkaline. Other potential sources of chemical contamination include sewage, ash from burned refuse, and spills of motor fuel, oil, and paint. With the exception of stormwater runoff from the construction site, none of these sources is likely to contribute significant amounts of harmful chemicals to the environment during a typical SSH construction project. However, accidental spills of large amounts of diesel, herbicides, or other wastes are always possible and may have a major impact on the environment.

After the dam is completed, impounded water dissolves many of the nutrients present in previously exposed soils. Any organic debris on the reservoir bottom will ultimately break down and go into solution as well. An additional nutrient source may be leachate from soils along the reservoir shoreline. The overall effect is heavy nutrient enrichment in the new reservoirs, which often stimulates primary production in the first few years. It usually takes several years before a new impoundment becomes physically, chemically, and biologically stable. The initial high levels of productivity may be followed by a decline for a period of up to 10 years (Ploskey 1981).

c. Biological effects. Biological impacts of SSH project construction may be direct and extended. Figure 15 illustrates the extensive secondary impacts of one construction activity, vegetation removal.

Some habitats and many of their associated organisms may be totally destroyed during such construction activities as deforestation, dewatering, temporary flooding of terrestrial habitats and wetlands, excavation of borrow pits, soil scraping, burying debris, crushing vegetation by vehicles, herbicide and insecticide application, burning, or the channelization of streams. Some habitats recover naturally after construction, while some habitats may be permanently lost.

Floodplain habitats are obviously the most directly affected by SSH construction. Habitat loss may be small in terms of total land area, but the ecological effects are often much greater, because lowland habitats and their associated plants and animals are selectively affected. This effect is particularly pronounced in arid regions, where the riverine habitat has a disproportionately high value.

Aquatic organisms may be affected in various ways during construction. Migrating fish may be prevented from moving upstream if passage is blocked during construction. Even a short period of blockage, if it occurs during spawning, migration or juvenile out migration, can eliminate one or more whole year classes. Fish may become stranded in the dewatered area when a diversion is made or when the reservoir is drained.

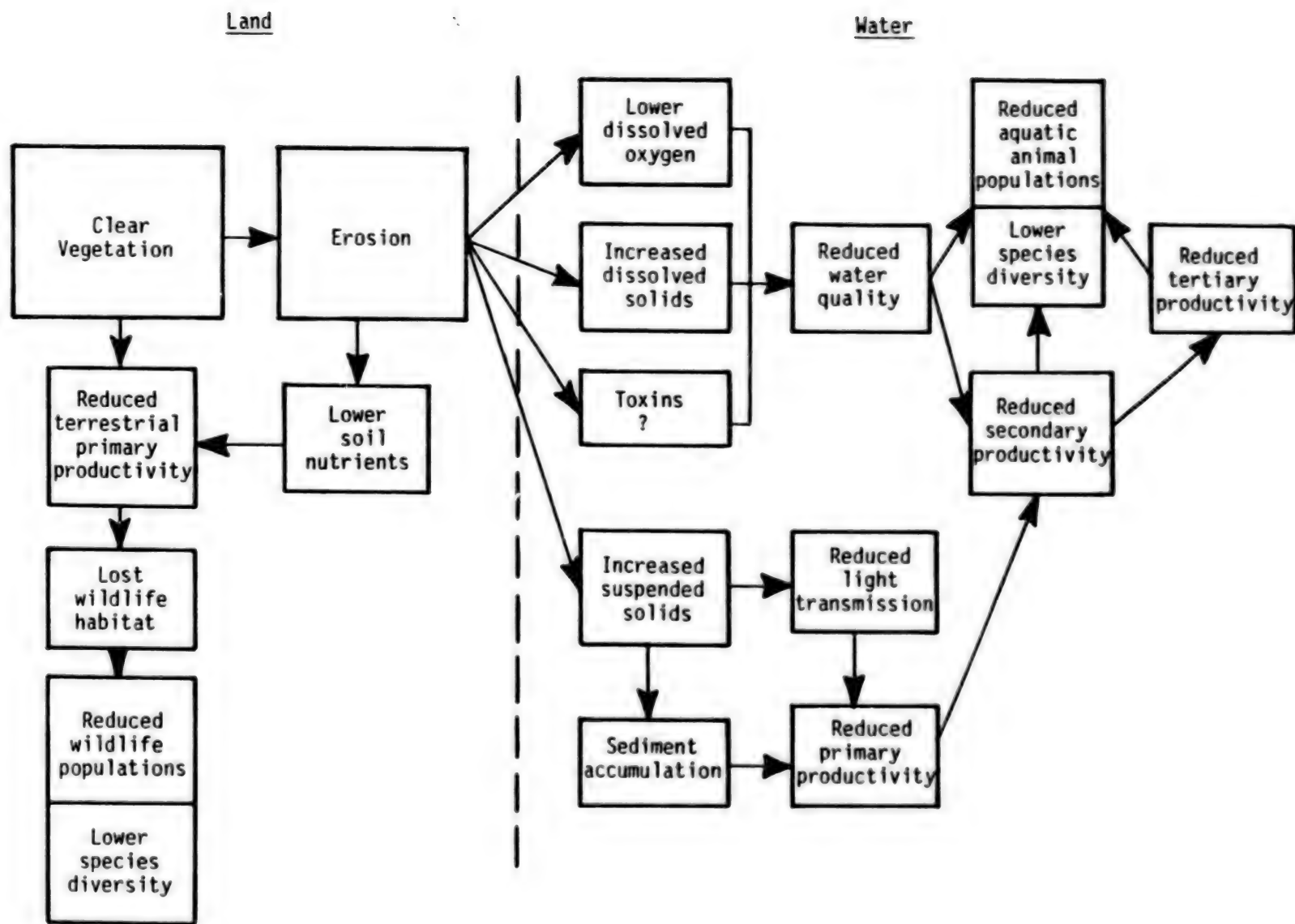


Figure 15. Some potential effects on fish and wildlife of removing vegetation (T. Lloyd Associates 1982).

Lowering reservoir water levels in a rehabilitation project will reduce the area suitable for spawning and subjects fish eggs to dehydration (Fig. 16). Drawdown may cause crowding. It may also result in the loss of rooted aquatic plants important as food or cover. Predators have a greater impact on fish populations when fish are concentrated in pools without cover. Competition for food among fish can become intense under these conditions. Blasting, if it occurs underwater or where a shock wave can be transmitted into water, may adversely affect fish (Coker and Hollis 1950; Hubbs and Rechnitzer 1952).

Substances toxic to fish originate in many ways. As equipment is cleaned, very fine particulate matter may be washed into streams, along with waste oil. Leftover pesticides, herbicides, and paints, or their containers, may be dumped into the water or on adjacent land; however, there are regulations against such disposal. The problem of stream pollution may be much worse if stream flow is reduced during dam construction.

The sediment mobilized during construction reaches streams with each rainfall or due to wind, landslides, and slope collapse. Suspended sediment results in turbid water, which may reduce visibility, clog gills, and disrupt fish spawning. If enough sediment settles out, it covers the bottom with a smooth, dense layer, smothering bottom invertebrates and leaving the surface generally unsuitable for spawning by salmonids and many other fish species. It will also reduce the suitability of overwintering habitat for juvenile salmonids.

Terrestrial animals are also affected by construction. Heavy equipment operation is noisy and may cause animals to avoid their usual habitats and watering areas. As the frequency of vehicular trips to the site increases, the danger of killing animals on the road increases. The transition from "jeep roads" to graded, wider access roads means that many more recreational users can reach the site. Both workers and visitors may engage in hunting and fishing, off-road vehicle use, and camping, which increases the risk of fires and other disturbances to wildlife and vegetation.

The removal of vegetation reduces available food supplies and reproductive sites, which may result in greater competition, migration to other sites, or loss of species from an area.

In the final stages of construction, the site may be replanted or landscaped. When the species used in landscape plantings and ground covers are introduced, they may be of limited value to local wildlife or even involve new weed species, plant diseases, and insect pests.

d. Seasonal and regional factors. The construction of a small scale hydroelectric facility usually takes from 1 to 3 years. The impacts of different phases of construction vary greatly from season to season at a given site and from site to site and region to region. If a reservoir is drained during a period of waterfowl use, the crowding of birds in other available habitats can be a problem. Extensive lowering of water levels in



Figure 16. Reservoir littoral zone exposed as the result of a drawdown (T. Lloyd Associates).

the spring can seriously affect fish spawning, while lowering in the fall will have little effect on spring spawning species. Soils are very mobile when wet; exposing large areas of soil to weathering during the wettest season likely will create a greater sediment problem than similar activities during the dry season. Selection of construction seasons to avoid environmental impact is not unlimited, however, because factors such as freezing of the ground, flood seasons, periods of high fire danger, and the contractors' scheduling conflicts may limit the degree of rescheduling that is feasible.

In anadromous fish regions a significant biological concern during construction is the relationship of the construction schedule to fish migrations. A reproductive season could be lost if fish migration occurs when passage facilities are incomplete or when the reservoir level is so low that the fish cannot pass through. In areas with winter ice, lake fish may be trapped under the ice in a reservoir much reduced in size.

In the Eastern United States, where many dams are being considered for rehabilitation, environmentally damaging impacts from construction may be less than in other parts of the country. Sites in the East often have existing access roads; many are in the downtown sections of cities and towns.

In the Southwest, there is an increased risk of fire during certain seasons. Then, projects should be prepared for fire suppression or scheduled to avoid the dry season.

e. Trade-offs. The main trade-offs in construction often involve the timing of the construction phases in relation to fish and wildlife needs. Moving rapidly in order to reduce costs and stay on schedule may conflict with the seasonal habitat needs of wildlife. On the other hand, delays in construction prolong the adverse impacts of construction on the physical environment, particularly soils. Timing of temporary flow diversions and cutoffs to avoid spring or fall migration times is desirable for anadromous fish, but may result in reduced flows later in the season when resident fish and wildlife are most vulnerable due to naturally low summer or winter water supplies.

Dredging is one way to increase reservoir capacity or remove accumulated sediment in intakes and canals, but the spoil must be transported and disposed of in a landfill. Flushing is an alternative to dredging in some situations; although there is no transportation of spoil or off-site disposal in this case, flushing means that downstream habitats may become inundated with sediment-laden water.

Measures to reduce the effects of visitors may involve trade-offs. For example, when a site is fenced to keep visitors out, animal access to water also may be restricted. If security lighting is installed, nocturnal animals may become disoriented.

f. Mitigation. Mitigation measures for construction impacts fall into two general categories: (1) measures designed to avoid or at least minimize a problem, and (2) remedial measures aimed at improving a degraded condition. Soil conservation measures, such as seeding ground stripped of vegetation, are an example of the first category of mitigation measures. Remedial measures include cleansing gravel beds clogged with sediment to restore salmonid spawning habitat or removing silt washed into a stream by dredging. These techniques are discussed further in the Mitigation Handbook.

4.3 REFERENCES

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5. FACILITIES-RELATED IMPACTS

There are five principal components of a SSH facility (Fig. 17), as follows:

1. Water supply;
2. Energy conversion;
3. Energy distribution;
4. Support facilities; and
5. Control systems.

For nearly all SSH plants, the water supply is provided by a dam or some sort of stream diversion structure. The dam also serves to increase the head. When stored water is used to produce electricity, gates are opened and the water is channelled toward the turbines. Gates are either part of the dam structure itself, as with a diversion dam, or they are in intake structures, somewhat removed from the dam. In either case, the intake and the waterway leading to the turbine are protected from debris by screens or similar devices. The waterway can be an open channel, though it is very often a pipe or a penstock. When the water reaches the turbine it usually is confined in a casing, although so-called open-flume settings are also used. After passing through the turbine, the water flows down through an expanding section of the waterway referred to as the draft tube, which leads into the tailrace. The tailrace eventually joins the natural stream channel, sometimes a considerable distance below the dam.

The electrical generator is usually located close to the turbine, connected to it by a drive shaft. Controls regulate the flow to the turbine and, hence, generator output. Electricity is conveyed to the power grid on transmission lines. Support facilities associated with a SSH plant include roads, a parking lot, and perhaps miscellaneous storage and service buildings, depending on the size of the plant and local needs.

Dams and impoundments, spillways, intakes, waterways and their controls, powerhouses, auxiliary equipment, and turbines are the principal components of a SSH facility. In this chapter, the characteristics and environmental impacts of each of these components is discussed, except for turbines, which are covered in Chapter 6.

Dividing the text into discussions of individual project components is somewhat unrealistic because facilities ordinarily are interrelated in a SSH project. The way different project configurations are set up is discussed in Chapter 3, the operation of components together is discussed

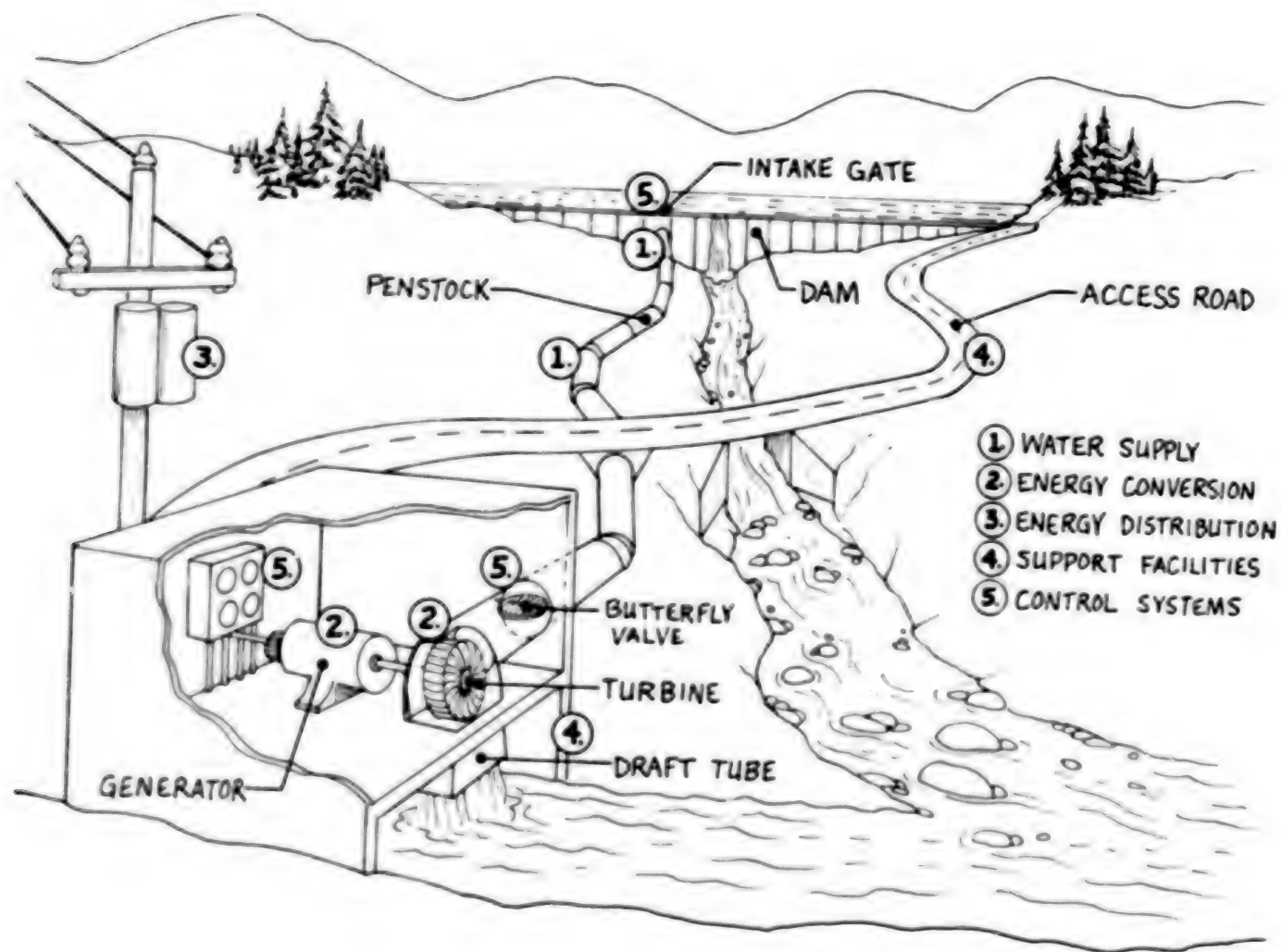


Figure 17. Basic elements in a hydro plant (T. Lloyd Associates 1982).

in Chapter 7, and impact assessment of SSH projects is discussed in Chapter 8.

5.1 DAMS AND IMPOUNDMENTS

5.1.1 Description

Dams create head and stabilize flow but they are not always necessary for hydroelectric generation; turbines can be installed in diversion ditches and wastewater outfalls. Lake taps, in which a conduit is constructed to carry water from a natural lake to a powerhouse at a lower elevation, also eliminate the need for dams.

Dams are most often classified by primary function (i.e., storage, diversion, or detention). The water in the impoundment often is used for several purposes, such as water supply, flood control, and recreation.

Dams are also classified according to the materials from which they are constructed (Fig. 18). The most common construction materials are earth, rock, and concrete, but there are many examples of timber, steel, and masonry dams. The selection of construction materials is based on the anticipated use of the impoundment, availability of various materials, on-site soil and geological conditions, hydrologic conditions, and spillway requirements. Earth, rock fill and concrete dams are the most common types in use for SSH projects.

5.1.2 Engineering and Economic Considerations and Trade-offs

The major engineering and economic considerations associated with dams are summarized in Table 4. The natural characteristics of a site, particularly its topography and geology, as well as the intended use of the impoundment, dictate the design and choice of materials for a new dam. Earth and rock fill dams are often the most economical to build because of the availability of fill material and the required construction equipment. Furthermore, foundation requirements are less stringent for earth and rock fill dams than for other types of dams. Many earth and rock fill dams have a long life span; however, overtopping and dam erosion is a serious potential hazard, making spillway design critical. Also, earth dams are not well adapted to fluctuating water levels because periodic wetting and drying of the dam surface can weaken the structure and contribute to dam failure.

Various types of concrete dams are widespread in the West and are economical where sand and gravel materials are available. In rugged terrain, soil is often scarce; thus, concrete dams are more economical to build in these areas than earthen dams. Water levels can fluctuate without damage to concrete dams, providing operators with more flexibility in water storage.

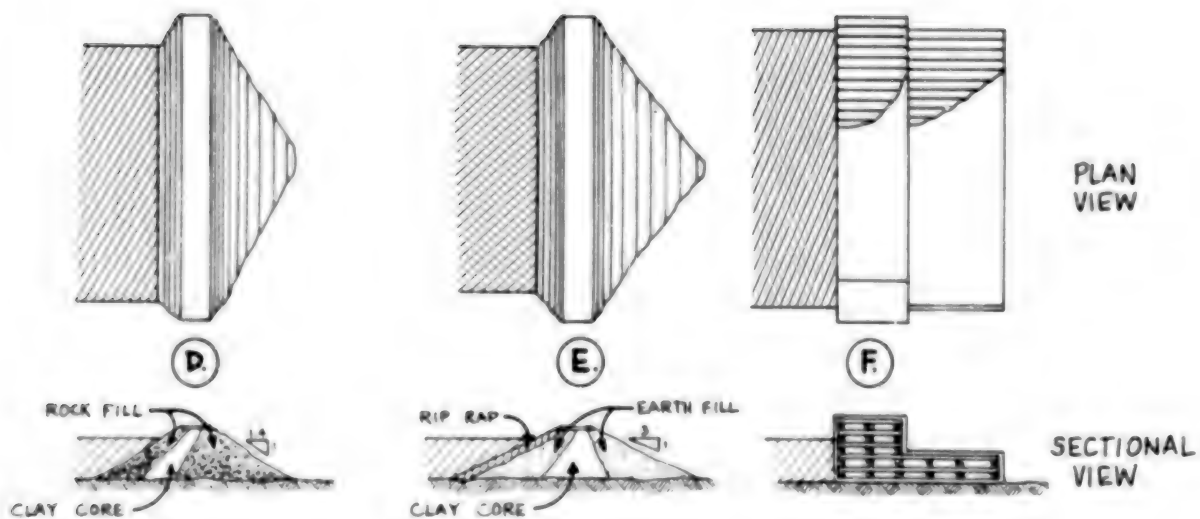
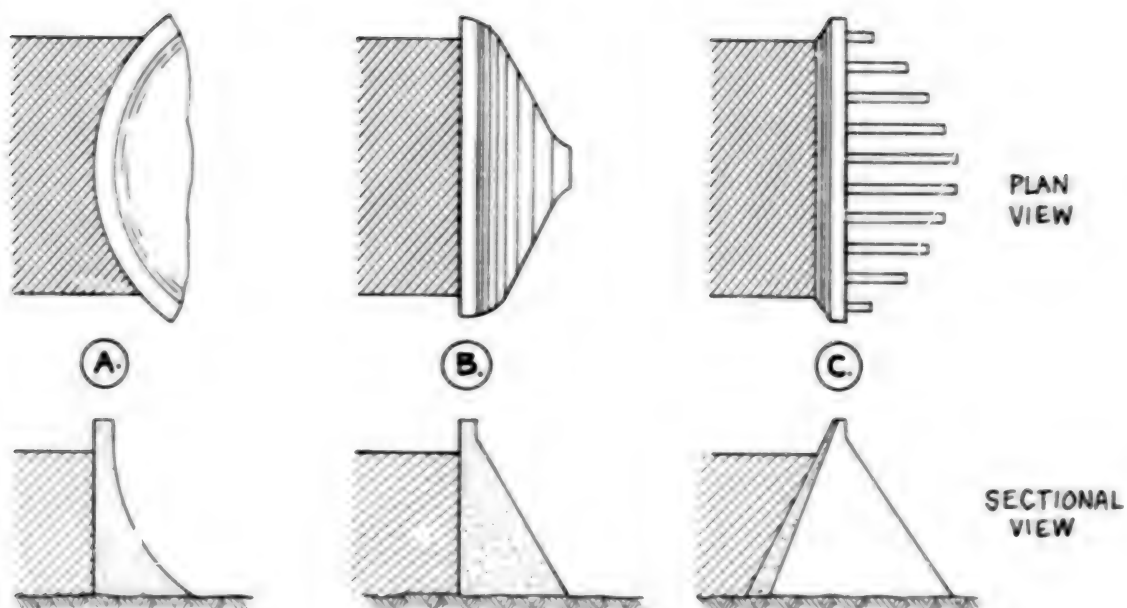


Figure 18. Major types of dams (Clay 1961). A. Concrete arch; B. Concrete gravity; C. Buttress; D. Rock-fill; E. Earth-fill; F. Timber crib.

Table 4. Major engineering and economic considerations for dams (T. Lloyd Associates).

Construction material	Description	Relevance to SSH	Engineering constraints	Economic constraints
Earth and rock fill	Utilize compacted earth and rock or combination of both. Many types utilize impervious material, often in upstream facing, sometimes within core. Steel plates, concrete slabs, or impervious soils have been used for this purpose.	Most common type today. Used for flood control, irrigation, water supply, and other purposes.	Can be constructed on foundations that are unsuitable for other types of dams. Earth and rock fill dams depend on their mass for stability. Spillway design is critical for safety.	Availability of large high performance earth moving equipment, together with availability of building material, makes this type popular.
Concrete gravity	Gravity dams depend on their mass for stability and can be straight or curved.	Many such dams constructed for flood control and irrigation, especially in the West.	Gravity dams usually require rock foundations. When gravity dams are located on a pervious foundation, seepage must be controlled to prevent excessive lift pressures and maintain integrity of the foundation.	Generally monolithic structures requiring massive amounts of concrete, possibly resulting in excessive expense.
Concrete arch	Arches transmit most of the water load to the dam foundation and/or abutments.	Generally for high dams. Many built in 1920's.	Narrow canyons with steep, strong walls are best suited for arch dams because the force is transmitted to the abutments.	Can be thinner than gravity dams.

Table 4. continued.

Construction material	Description	Relevance to SSH	Engineering constraints	Economic constraints
Concrete	Buttress dams utilize a sloping membrane, generally of concrete, to transmit hydrostatic forces to a series of structural buttresses placed normal to dam axis.	Generally for high dams, but suited to wide valleys with gradually sloping abutments.	Can be built on rock or sound alluvium. Can withstand minor settlements or deformities by designing adjacent slabs with flexible joints.	Require less concrete than gravity dams of the same size but require more framework for construction.
Masonry	Rubble or stone laid in mortar.	Used in both gravity and arch dams.	Similar foundation requirements as for concrete dams.	High labor costs and improved concrete technology have made this type of dam uneconomical. None built in last few decades.
Timber and rock-crib	Timber or timber facing with rock core.	A number of small timber dams constructed in West and Northwest; some in New England.	Most timer dams are less than 6 m high but a few have been as high as 18 m. Dams higher than 3 m are rock filled crib.	Short life span due to rotting timbers.
Stonewall-earth	Upstream earth section with vertical or nearly vertical stacked stone.	Several hundred already exist in Northeast U.S.	Generally less than 9 m high; most are 100 to 200 years old.	High labor costs and possible lack of suitable stone.

Timber dams are common where the supply of wood is great, such as in the Northwest. Timber dams are typically less than 6 m high and require considerable maintenance.

5.1.3 Environmental Effects, Trade-offs, and Mitigation

Dams and impoundments have numerous direct and indirect effects on aquatic and terrestrial plants and animals. Because dams are often designed with a life span of at least 100 years, these effects should be considered carefully. However, few broad generalizations can be made about the impacts of dams and impoundments. Some result in drastic alterations of fish and wildlife habitat with far ranging consequences to the resource while other projects, such as a low dam on a minor tributary, may have little or no effect on fish and wildlife beyond the immediate boundaries of the project site. The most significant impacts attributable to SSH are likely to arise from: (1) projects that require new dam construction, particularly when the dam is to be located on the main stem of a river or where there are no other dams downstream; (2) SSH projects founded on the reconstruction of breached dams; and (3) in cases where an existing impoundment is enlarged by raising the height of the dam to increase head or pondage for a SSH project.

Dams alter the hydrology of flowing streams and, by doing so, alter the physical, chemical, and biological conditions both in the impounded area and downstream. For example, dams interrupt sediment and nutrient transport, block the route of migratory fish, and often degrade water quality. These actions usually have negative effects on fish and wildlife, but dams and impoundments can also have beneficial effects. For example, stabilized flows downstream may increase the production of fish food organisms and, where high spring flows scour the bottom, spawning habitat can be improved. Mundie (1979) reported that an impoundment on Vancouver Island, B.C., was responsible for an increase in egg-to-fry survival of chum salmon by stabilizing winter flows. Coho salmon also benefited.

In the following sections the effects of dams are discussed in two general categories: (1) the physical, chemical, and biological changes that occur within the impoundment; and (2) the changes that occur downstream.

a. Physical and chemical effects within the impoundments. When flowing water is impounded, its physical and chemical characteristics almost always change. Many factors affect the degree of change, but water detention time in the reservoir is usually among the most important. The length of time water is detained in the impoundment is a function of: (1) the volume of the reservoir; (2) the amount of inflow from precipitation, surface, and ground water sources; and (3) the amount of water lost to planned releases, seepage, and evaporation. Large reservoirs sometimes detain water for several years, whereas small, low head diversion impoundments usually detain water for only a few hours or days.

When detention time is short, temperature and other physical and chemical characteristics of the outflowing surface water usually differ little from those of the inflowing water. However, when detention time is long, impounded water can become warmer than inflowing ground water or surface water that is shaded by riparian vegetation. Because of the relation of water temperature to water density, a layer of warm, less dense surface water (the "epilimnion") forms. This phenomenon occurs in both natural and manmade lakes and is called thermal stratification (Fig. 19). The layers of stratified lakes may be stable and well defined because density differences preclude mixing. Warmer water overlays colder water during the summer but, in winter in northern climates, the reverse is often true.

Thermal stratification is important because it has a direct effect on the chemical and biological conditions in a lake. During the summer, the cold bottom waters often contain low concentrations of dissolved oxygen and may have high levels of ammonia, hydrogen sulfide, and toxic substances that diffuse from bottom sediments. In contrast, the surface water is warm, biologically active, and usually low in toxic substances.

Although low head impoundments are usually too shallow to become stratified, water quality should be considered, particularly for projects involving new dams or when an impoundment is to be deepened by adding to the height of an existing dam. The type and depth of intake(s) used has a profound effect on the extent of stratification in the reservoir and its downstream effects (Section 5.3).

b. Biological effects within the impoundment. Aquatic organisms in downstream river reaches are dependent on the physical, chemical, and biological processes occurring upstream (Cummins 1975). Early growth forms of mayflies and other aquatic insects, hatched in headwater tributaries, drift downstream (Waters 1962), ensuring the continuance of mainstem communities. The river drift also contains eggs and larvae of some fish species, as well as detritus and nutrient-rich by-products of animals upstream. Impoundments weaken or break the link of trapping detritus and other drift components. They interfere with downstream recruitment and can impoverish downstream areas by altering or disrupting nutrient cycles. On the other hand, some reservoirs are nutrient rich (eutrophic) and may significantly increase the nutrient loads downstream. Thus, it is important to consider reservoir conditions and release mechanisms in assessing environmental impacts of specific impoundments.

Impoundments may reduce the number of lotic (flowing water) species by reducing stream habitat diversity. Flowing waters, characterized by pool and riffle sequences, provide a variety of current velocities, depths, and associated substrate materials within a given river reach. Species diversity among fish, macroinvertebrates, and aquatic vegetation is higher under such conditions than in standing water. However, on a watershed basis, impoundments have the effect of increasing habitat diversity in an aquatic system; therefore, overall species richness in the watershed is often increased by the addition of lentic conditions, providing that undue adverse environmental conditions do not develop in the impoundment.

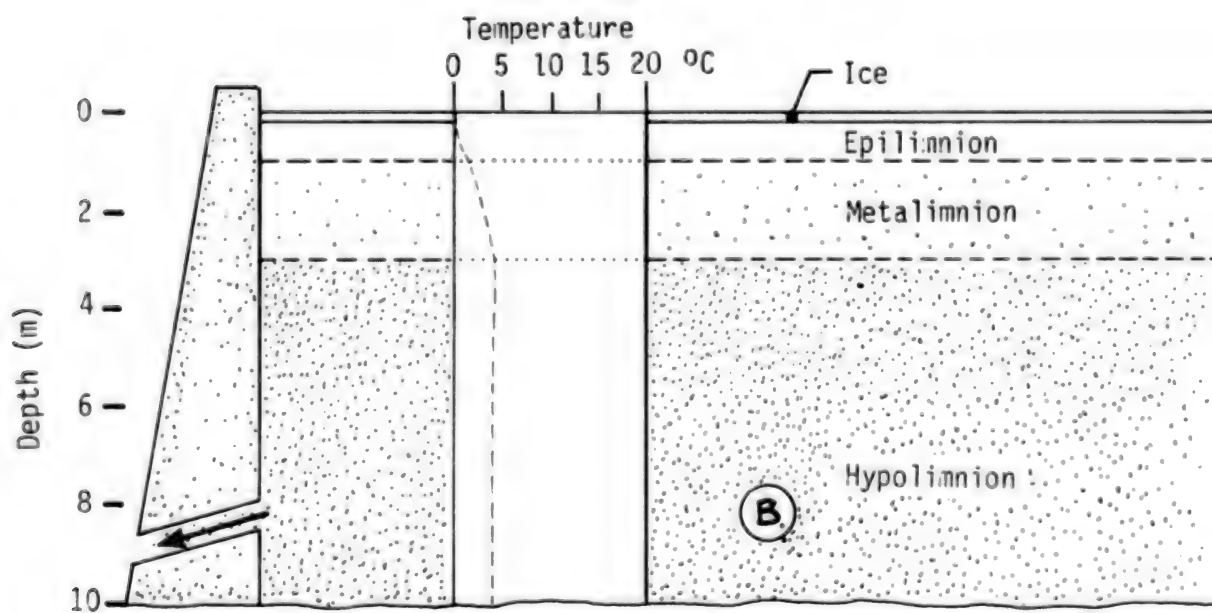
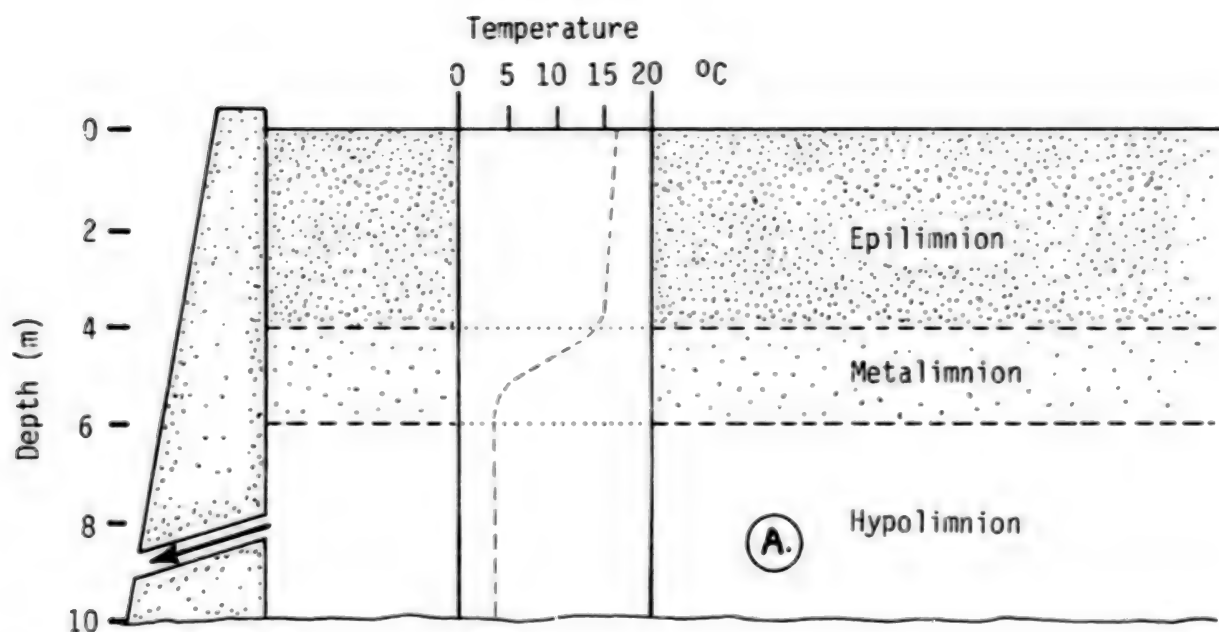


Figure 19. Thermal stratification in a reservoir in (A) summer and (B) winter (T. Lloyd Associates).

Impoundments may enhance fisheries, particularly new ones, which may be very productive. In some instances, the high productivity is caused by the release of minerals from newly flooded soils. However, it has also been attributed to the presence of submerged stumps and debris from clearing operations, which provide a ideal habitat for fish and fish food organisms (Ploskey 1981).

Damming a river rarely affects only a few species; it usually results in changes in the composition and structure of the entire aquatic community. For example, planktonic algae and associated zooplankton thrive in impounded water and provide food for fish; this can lead to a substantial increase in the numbers of fish species and/or fish productivity. However, the combined effect of respiration and biochemical oxygen demand caused by very large plankton populations, which often develop in nutrient-rich impoundments, deplete the oxygen concentration, eliminating fish species that require well oxygenated water. Many fish kills have been attributed to this problem.

Riverine fish include obligate and facultative species (Holden 1979). Obligate species depend on flowing water (lotic) habitat to provide the necessary bottom substrate for spawning, food, and cover. Examples of these fish include Pacific salmon, paddlefish, and blue sucker. Facultative species, such as largemouth black bass, yellow perch and carp, usually have less exacting food and/or spawning requirements. Many facultative riverine species thrive in the warm surface waters frequently characteristic of impoundments whereas many obligate species such as salmonids do not. Therefore, when a river is dammed, obligate species may ultimately be replaced by facultative species. Change of species composition in newly impounded waters can occur rapidly or take several years. The disappearance of species is usually gradual if reproduction is curtailed (as opposed to eliminated) or if the species lose out because of increased competition.

Significantly, approximately 60% of the fish presently listed as endangered or threatened in the U.S. are obligate riverine species (Holden 1979). Dams present a host of potential problems for many fishes, particularly migratory species. In the Pacific Northwest there are six major concerns regarding dams (Korn 1968, cited by Kelly 1980). These are:

- (1) Dams, as physical barriers, may prevent or delay adult fish from moving upstream to spawning grounds.
- (2) Inundation of spawning grounds may make them less useful as rearing areas for young fish.
- (3) Lack of water currents in the impoundment may confuse juvenile fish and prevent or delay downstream migration.
- (4) Facilities for passing juvenile salmonids downstream may not be provided or may not be very effective.

(5) Impoundments may harbor large populations of predator fish, resulting in poor survival of salmonids.

(6) Water quality in impoundments and downstream areas may adversely affect adult or juvenile salmonids.

The areas where these six concerns are frequently an issue are the anadromous fish regions (Fig. 20). A seventh concern, turbine mortality, is discussed in Chapter 6.

c. Impacts on terrestrial ecology. Inundation of lands that formerly supported terrestrial plants and animals is the most obvious impact associated with a new impoundment. Impact assessments of new impoundments should consider both game and nongame species. Individuals displaced by an impoundment cannot normally be accommodated easily on adjacent lands because those habitats usually are at or near carrying capacity (MacArthur 1965). Not all new impoundment impacts are negative. Many impoundments enhance waterfowl, wading, and shorebird habitat, as well as provide habitat for amphibians, many reptiles, and some mammals. The ultimate significance of habitat loss is a function of (Ortolan 1973):

- The type of existing vegetative communities (e.g., coniferous forest, chaparral, or grassland).
- The kinds and numbers of wildlife inhabiting the region to be flooded, particularly if they include rare or endangered species.
- The importance of the lost habitat to the region.
- The kinds and numbers of wildlife in neighboring regions.

d. Downstream impact. Flow regulation associated with dams can result in significant changes in depth of flow, duration of flow, current velocity, sediment transport, water temperature, and water quality (Walburg, undated). As shown in Figure 21, flow regime modifications may result in habitat changes with either favorable or unfavorable consequences for downstream benthic organisms. The nature and extent of the physical, chemical, and biological changes downstream of an impoundment depend on conditions in the impoundment and the way in which water is discharged. The effects of these factors may be modified by downstream influences, such as inflow from ground and surface water and streamside vegetation. However, the characteristics of the impounded water and the pattern of releases from the impoundment are very important.

Dams may reduce the seasonal and daily temperature fluctuations of the downstream water. Figure 22 shows the thermal characteristics of two branches of the same river. In one (Fig. 22B), the downstream flows are regulated by a dam; in the other (Fig. 22A), the water flow is unimpeded. Temperature influences the migratory instincts of salmon, herring, and other anadromous species as well as egg development and metabolism.



Figure 20. General range of major anadromous fish stocks (Parkhurst 1979).
 A. Salmon and steelhead trout; B. Shad, C. Striped bass.

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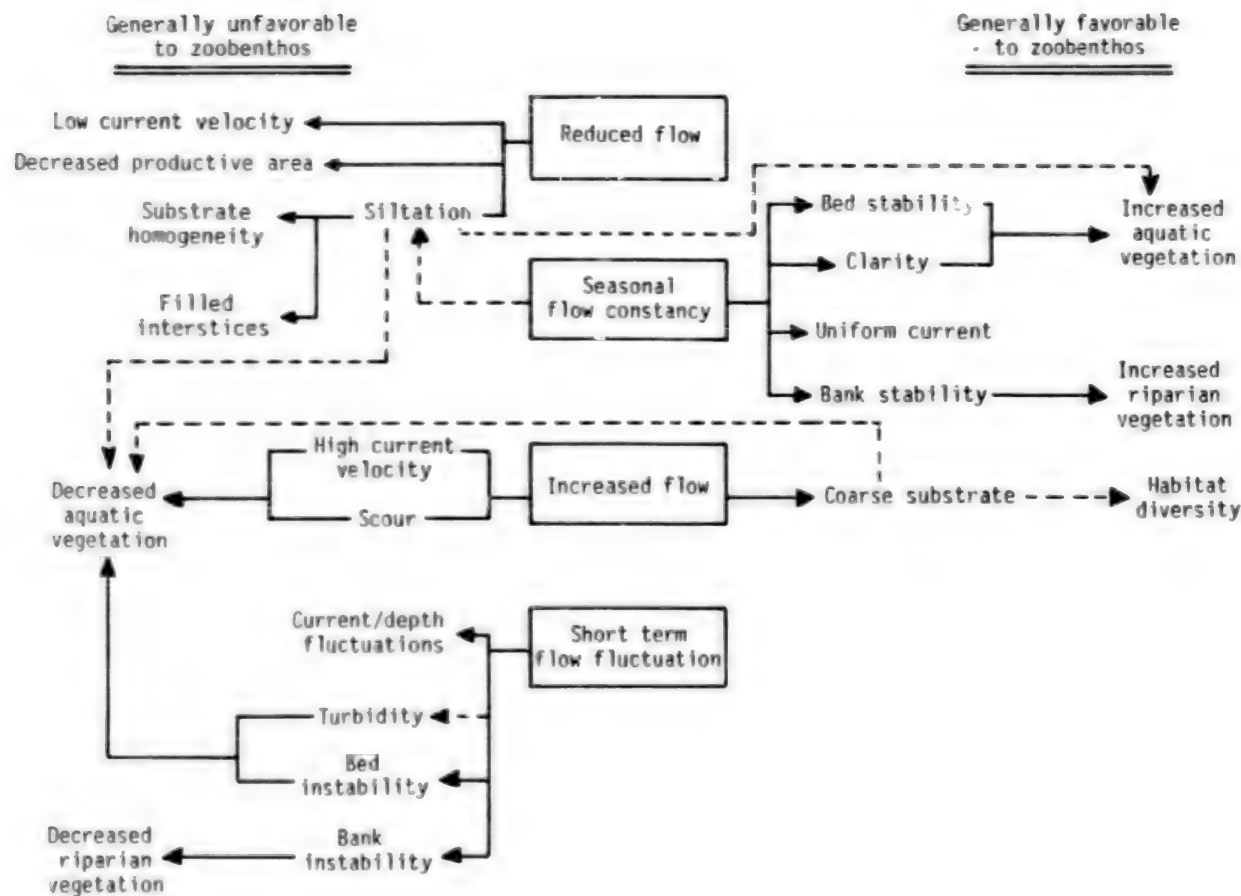


Figure 21. Potential effects of flow regime modifications below dams on ecological factors important to erosional zone zoobenthos (Ward and Stanford 1979).

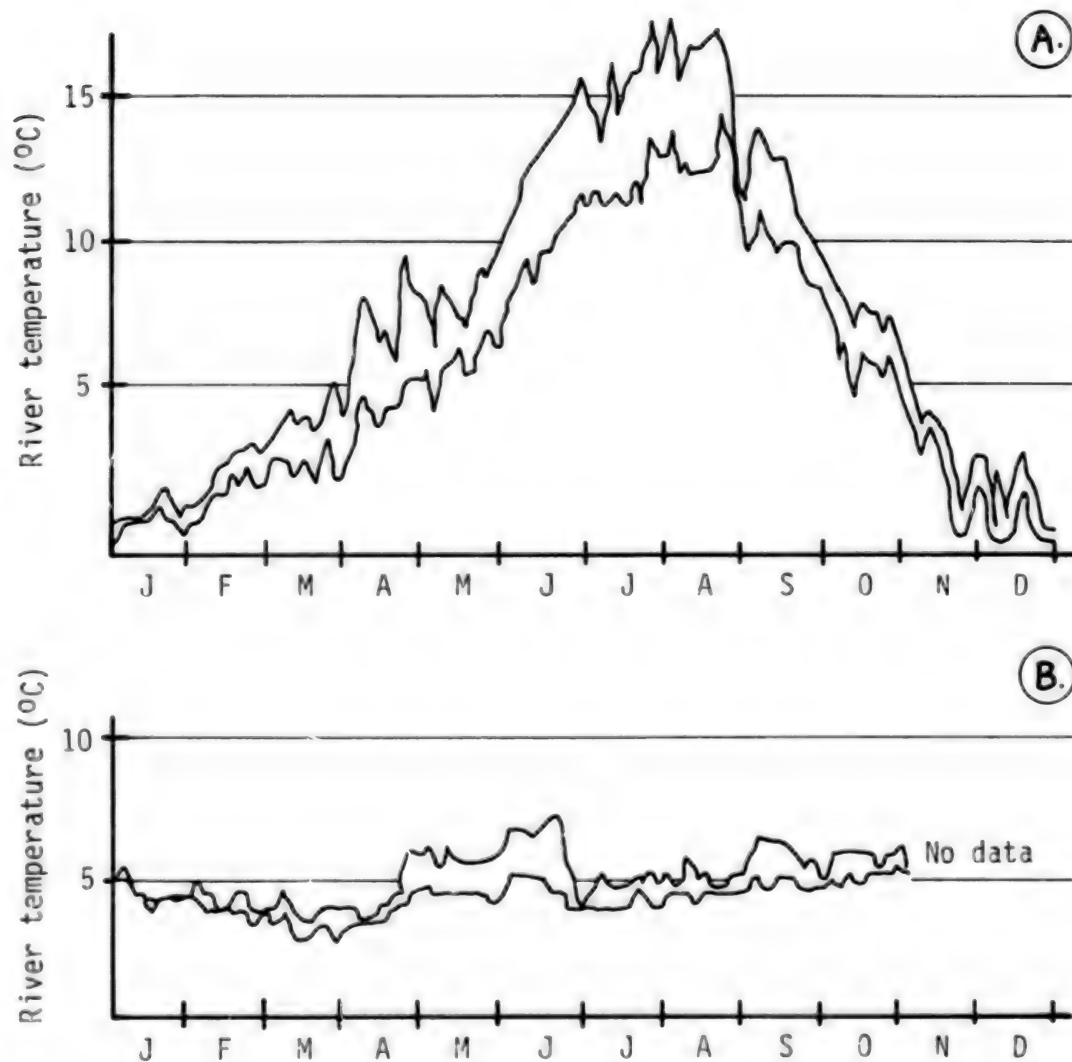


Figure 22. Thermal regimes of the (A) unregulated Middle Fork and the (B) regulated South Fork of the Flathead River during 1977 (Ward and Stanford 1979).

Temperature can also affect the solubility of oxygen and the toxicity of some substances to fish (Bell 1973, Morgan 1980). The temperature of releases from stratified impoundments varies with the depth from which the water is withdrawn. In stratified impoundments, water may come from the surface (epilimnion) or from the bottom (hypolimnion), or a mixture of the two. Cold deepwater releases from an impoundment may adversely affect warm water species of aquatic insects and fish by reducing downstream temperatures by as much as 20°C (Ward and Stanford 1979). Conversely, cold water releases may allow managers to create cold water put-and-take fisheries.

Changes in temperature can be sudden (when a large amount of water is released for peaking power) or gradual (when water is released from recreation impoundments). Large discharges often have drastic consequences, causing temperature shock and mortality. The effects of slower discharges extend over a much longer time period and are more subtle, but may be just as great. For example, releases from a dam on the Saskatchewan River resulted in the loss of 15 species of mayflies, important fish food organisms in the tailwaters (Lehmkuhl 1972). Constant cold water releases eliminated the specific temperature sequences necessary to hatch eggs. The releases also delayed the spring temperature rise so that insects were unable to complete the growth and development stages necessary to reach sexual maturity.

Downstream physical and chemical conditions often are very different from those in waters flowing into the impoundment. Downstream aquatic communities are affected by the chemical nature of releases from impoundments. For instance, clear, cool, nutrient-rich, deepwater releases favor filamentous green algae, especially if the flow is stabilized (Stober 1963; Ward 1976 cited by Walburg et al., undated). The invertebrate communities under these conditions often are dominated by midge and black-fly larvae because these groups are tolerant of water low in dissolved oxygen (Walburg et al., undated). On the other hand, releases from the warmer epilimnion, containing dense plankton populations, often support an abundance of net spinning caddisflies and other filter feeders (Muller 1962). Algal populations downstream from such impoundments vary, depending on the availability of nutrients. Water quality in impoundments that are not truly stratified may still be quite different between the top and the bottom.

e. Regional and seasonal factors. The nature and degree of impacts caused by impoundments varies from region to region and from season to season. Much depends on how external factors, such as existing users, climate, topography, or geology, affect the water quality in the impoundment. Regional differences in fish and wildlife resources also are important. Dams located where anadromous fish are present have a much greater potential for adverse impact than those in locations where passage of non-anadromous species is of no concern. Some impacts exhibit seasonal variation. Many impoundments, for example, discharge poor quality water during the summer, water so low in dissolved oxygen that pollution-intolerant species of fish avoid the tailwater area. However, when the

tailwater contains high levels of dissolved oxygen in winter, the same fish species may be attracted to it. In some instances, the somewhat warmer water temperatures that characterize deep water wintertime releases actually enhance the growth and development of fish and fish food organisms.

The importance of riparian habitat loss due to flooding varies from region to region. Where valleys are narrow and there is little streamside habitat to begin with, creating a reservoir with steep, rocky shorelines can have serious adverse consequences to wildlife species that nest or depend on riparian vegetation for food and cover. In arid regions, impoundments flood the most productive soils on which the majority of wildlife species indirectly depend. Wildlife studies in southeastern Washington suggested that an impoundment resulted in a local loss of nearly 14,000 birds during the summer and 30,000 birds in the winter (Lewke and Bass 1977).

f. Trade-offs. Trade-offs concerning the selection of a particular dam type can involve operation and maintenance issues (see Chapter 7). For example, earthen dams often have less affect on the natural environment than other types of dams. They provide a gently sloping shore on the upstream side and good surface on which animals can cross the lake. But earthen dams frequently result in off-site problems, such as borrow pits and abandoned haul roads, and they are more subject to catastrophic failure than other types of dams. Concrete dams require less off-site activity, but much more on-site activity, during their construction.

Most potential SSH projects offer a variety of alternatives, each of which involve trade-offs. However, economics or site limitations often rule out all but a few of the alternatives. For instance, SSH might be economically feasible at an existing impoundment if the head can be increased. This might be accomplished by elevating the spillway or deepening the impoundment. Either approach has economic, as well as environmental, trade-offs. Elevating the spillway could inundate spawning areas or destroy associated wetlands; dredging may cause toxic materials to become resuspended.

g. Mitigation. It is possible to mitigate partially the major impact of dams, the blockage of fish movement, by adding fish passageway facilities. These are discussed in the Mitigation Handbook.

5.2 SPILLWAYS

5.2.1 Description

Spillways carry off the overflow from a reservoir in order to protect the dam from being overtopped. Most of the discussion in this section concerns spillways that discharge surface water, the type most commonly used in SSH, rather than those that discharge bottom water through sluice gates or valves located at the foot of a dam.

Spillways vary considerably in design, but all of them fit into two general categories: uncontrolled and controlled. Uncontrolled spillways, such as weirs, are designed to automatically maintain a reservoir at some particular elevation. Controlled spillways permit water levels to be manipulated by opening and closing gates. Many dams have both types of spillways.

a. Uncontrolled spillways. Uncontrolled spillways may be located on the dam or near it (Fig. 23). There are six major types (U.S. Fish and Wildlife Service 1977): overflow; chute; saddle; side channel; shaft or morning-glory; and siphon.

Overflow spillways are located on the dam. They are widely used on concrete dams, but cannot be used on earth and rock-filled dams unless the spillway is built within a concrete section of the dam. Overflow spillways eliminate the cost of excavation and construction in valley walls adjacent to the dam. Properly designed, overflow spillways can maintain water levels within a narrow tolerance.

Chute spillways and saddle spillways are separate from the dam. The chute spillway has a lined channel and is commonly used with earth and rock-filled dams. Saddle spillways use a natural topographic depression instead of a man-made channel. The depression must be underlaid by impermeable bedrock to avoid any erosion that might lower the spillway elevation and, thus, reduce the volume of the impoundment. Side channel spillways are located adjacent to dams.

Shaft (morning-glory) spillways begin slightly upstream from the dam. The water enters through a funnel and makes an L-shaped turn through a conduit that extends through the dam. This type of spillway is commonly used with earth-filled dams and in situations where topography precludes chute or side-channel spillways. Some shaft spillways have gates at different levels.

Siphon spillways discharge water from the top and bottom of the impoundment through a closed conduit that functions as a siphon. Siphon spillways are suitable for almost any type of concrete dam and for earthen or rock-filled dams, provided that the spillway inlet is not located on the dam.

Any of these types of spillways can be used as an emergency spillway. An emergency spillway prevents the dam from being overtopped during extreme conditions or, in some instances, during floods of lesser magnitude. The crest of an emergency spillway is usually higher than that for the principal spillway.

b. Controlled spillways. Controlled spillways enable the manipulation of water levels in impoundments. Three basic kinds of controls are used: crest controls; crest gates; and sluice gates or valves.

Crest controls (Fig. 24), which regulate spillway elevation, include flashboards, tilting gates, bear-trap crests, and drum gates. Flashboards

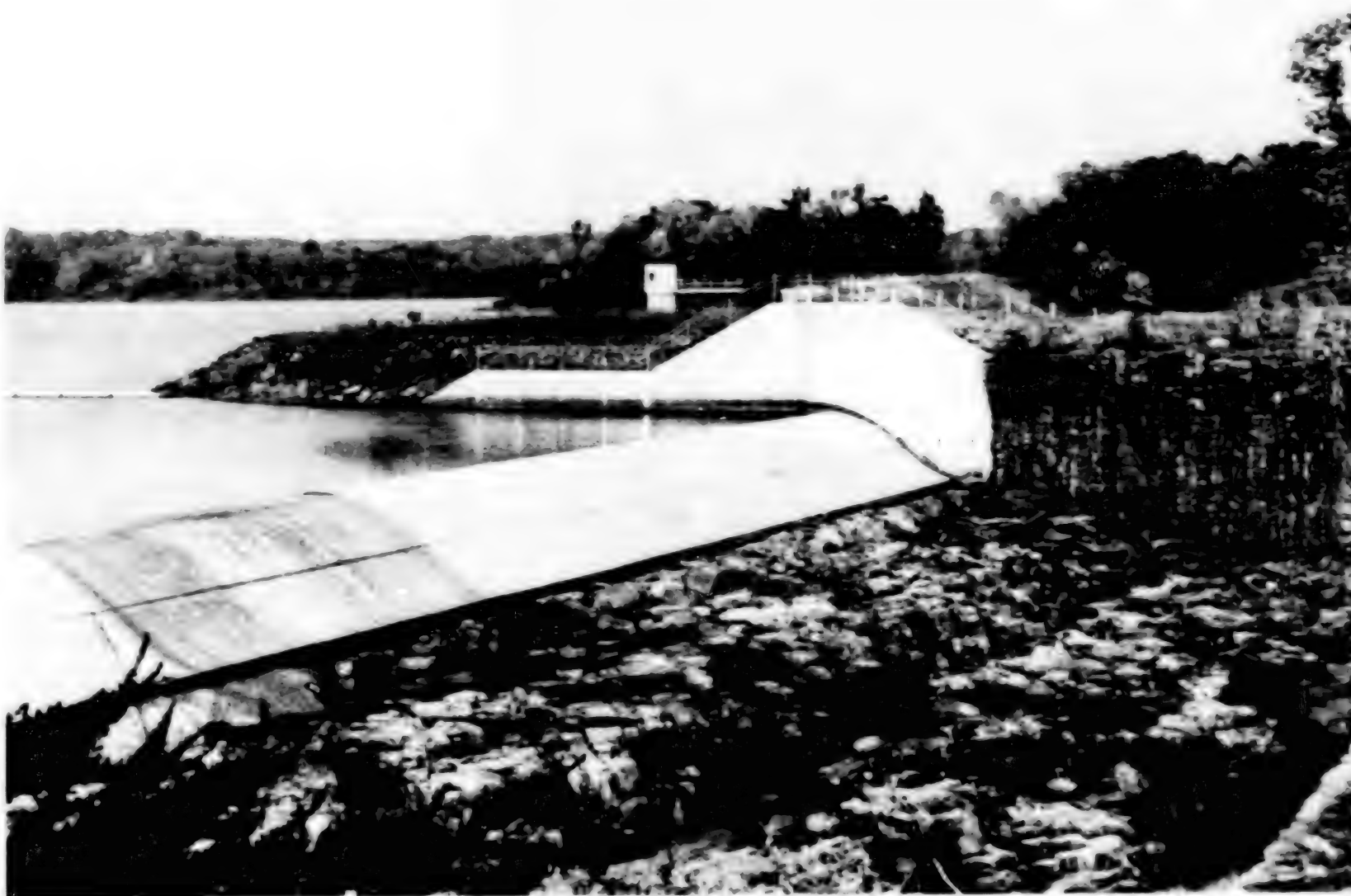


Figure 23. An uncontrolled spillway at Lake Nockamixon, Bucks County, Pennsylvania (T. Lloyd Associates). Note the trash boom floating in the reservoir at the left side of the photo.



Figure 24. Example of a crest control gate (Allis-Chalmers, Inc.).

are the most common type of crest control in small impoundments. Although water is intended to spill over the top of crest controls, there may be considerable leakage, especially with flashboards.

Crest gates discharge water from some distance below the surface of the impoundment. The principal types of crest gates include: (1) those that move in a vertical plane, such as sliding gates; (2) those that pivot on an axis, such as taintor gates; (3) those that roll up an inclined plane, such as caterpillar gates; and (4) stoplogs or pins, which sometimes serve as crest gates on low head dams.

Sluice gates and valves control low level releases (sluices) and are used on many dams. Sluices may be operated occasionally, such as during low flow conditions when there is insufficient water flowing over a dam, or continuously, when it is desirable to regulate the flow closely. Many of the gates commonly used as crest gates also are suitable as sluice gates. These include plain sliding and wheeled gates. Butterfly and needle valves are used at high head dams when maximum control of releases is desired.

5.2.2 Engineering and Economic Considerations and Trade-offs

The selection and location of a spillway is influenced by numerous factors, including the type of dam, the site topography, geologic and foundation characteristics, and the magnitude of expected flows, particularly floods. If the objective is to raise the head at an existing dam, the structural soundness of the dam must be taken into account because it must be capable of withstanding the extra pressure and weight created by the water behind spillway gates.

Water plunging over a spillway has considerable erosive potential. An unprotected stream bottom can be eroded to the extent of undermining the dam, resulting in its collapse. Because of this possibility, spillways are designed with plunge pools and special structures to dissipate hydraulic energy.

Spillway costs are dictated by the size of the planned, maximum flood the spillway is expected to control and the type of spillway selected. Operation, maintenance, and the amount of site modification necessary to accommodate the structures also affect the cost. Many of the crest control gates, such as caterpillar and roller gates, are large and relatively elaborate; they require substantial machinery to raise or lower them and may be far too costly for low head dams. Taintor gates are the most widely used crest control gates on low head dams because they are usually the least expensive.

Controlled spillways offer economic and operational advantages but, if they fail to operate properly, the dam and downstream area are jeopardized. Redundant or alternative spillways are often provided to minimize the flood hazard, but these may be costly (Creager and Justin 1950). Uncontrolled spillways operate automatically, thus reducing labor costs. They also have lower repair and maintenance costs than do controlled spillways. However,

these factors must be balanced against the value of being able to manipulate water levels and flows.

5.2.3 Environmental Effects, Trade-offs, and Mitigation

a. Physical and chemical effects. The velocity of water passing over a dam or through a spillway is relatively low at the top and increases rapidly toward the bottom. Depending on the spillway structure, a free fall of over 30 m is possible. Maximum water velocity is a function of the difference in head between the top and the bottom of the fall, the smoothness of the spillway, and the extent of the air-water momentum exchange (Copp 1968). Water at the bottom of a spillway is moving very rapidly when it strikes the tailwater of the dam, sometimes creating a zone of rolling turbulence with an evident hydraulic jump (standing wave). Such an environment increases the dissolution of gases in the water. Dissolved nitrogen concentrations of more than 130% of normal equilibrium levels (supersaturation levels) have been measured in tailwaters (Ebel and Raymond 1976). Along the Columbia River, where many spillways discharge from a given dam and there are many consecutive dams along the stream course, supersaturation increases cumulatively from one dam to the next. Losses of salmon and steelhead trout in this river due to the supersaturation have been severe in years of high spillage (Ebel and Raymond 1976).

The importance of supersaturation in SSH projects is uncertain. The probability of supersaturation increases with the increasing violence of the encounter between the falling water and the water in the plunge pool and, therefore, is a function of head, flow over the spillway, and the amount of water in the plunge pool. The supersaturation of water may also be contributed to by the turbines and conduits.

b. Biological effects. Organisms passing over spillways can be injured by strikes or impacts with solid objects (e.g., baffles, walls, or rocks in the plunge zone), rapid pressure changes, abrasion with the rough sides of the spillway structure, and the shearing effects of turbulent water. Bell and DeLacy (1972: 43-44) analyzed the results of many experiments with fish (mainly small salmonids) under various spillway-like conditions and found the following:

In constricted areas, where the rate of deceleration of water and fish could be controlled by baffles or walls, the survival rate quickly approached zero when the velocities exceeded 40 fps, and probably were as low as 70% in the 20-30 fps range. This may not have resulted from a direct strike but from shearing or recirculation through the same area. The survival rates of fish entering a pool from free fall were found to be 98-100% at velocities of 50 fps, 80% at a velocity of 60 fps, and probably zero at velocities of 80 fps and greater. Survival rates of fish entering a pool in a column of water, decelerating with the jet and without mechanical deflection, may equal survival under the best free fall conditions. Survival rates of fish entering a pool within a column of water, decelerating with the jet and

deflected by a baffle, is about 93%. Survival rates of fish through a hydraulic jump or large stilling pool in a single passage approaches the best condition of the jet, 93-98%. Survival rates of fish striking a fixed baffle or object approaches zero.

Data summarized in Bell and DeLacy (1972) show that, for various salmon species and rainbow trout, the height of free fall that can be survived depended on both species and size of fish. For example, in one experiment in which rainbow trout and coho salmon were dropped from a helicopter, both species had 100% survival at falls of about 15 m. However, at greater heights, the effects of species and size were evident, as follows:

	Height of fall	
	56m	99m
	- % survival -	
Rainbow (15-18cm)	98	98
Rainbow (30-38cm)	25	7
Coho (66-71cm)	50	0

No published studies were found on the effects of spillway, jet, or free fall passage on nonsalmonid fishes. It is likely that the same general principle of increasing mortality with greater violence of impact and turbulence applies. The interspecies differences in mortality rates could be large because salmonids typically inhabit fast moving streams where high turbulence and falls are part of the natural environment, whereas most warm water species normally do not encounter such conditions.

Copp (1968) points out that an object (fish) entrained in spillway flow can experience a substantial pressure reduction over a short period of time. If the spillway gate is located below the surface, a fish passing through the gate is adapted initially to the pressure at the depth of the gate opening. However, when it reaches the plunge pool, it is exposed to atmospheric pressure or possibly lower levels. This rapid reduction in pressure may result in swim bladder damage or gas bubble disease.

Another cause of injury to fish may be entrapment in the "rollers" of water (hydraulic jump) that develop at the base of the spillway. The longer a fish stays in such a place, the higher the probability of its being injured by impact or shearing effects. According to Johnson (1972), the force of high speed, turbulent water (shearing forces) can have a significant negative effect on fingerling survival (Table 5). Mortality rises sharply as fingerlings enter the stilling basin at velocities greater than 28 m/s; below 17 m/s shearing force mortality is zero.

Nitrogen supersaturation causes gas bubble disease in fish. Symptoms include disorientation, emphysema, gas emboli, lesions, exophthalmia ("popeye"), and death. The threshold level for significant mortality among

Table 5. Mortality of fingerling salmonids in a high-velocity jet, 10 cm nozzle (Johnson 1972).

Jet velocity m/s	length (cm)	Species mortality (%)		
		Coho	Chinook	Steelhead
17.7	20-23	^a	-	-
20.6	7.5	-	-	-
20.6	7.5-10	-	-	0.7
20.6	20-23	2.4	-	-
20.6	20-23	-	5.4	-
20.6	30	-	-	-
23.8	7.5	10.3	-	-
23.8	7.5	-	3.7	-
23.8	18-20	-	-	6.0
23.8	18-20	-	-	12.0
23.8	20-23	-	-	5.0
28.3	7.5	41.3	-	-
28.3	7.5	-	25.8	-
28.3	10	36.7	-	-
28.3	10-20	-	-	17.1
28.3	20-23	-	-	13.0

^aNot tested.

juvenile chinook salmon and steelhead trout occurs when nitrogen gas levels are about 115% of normal (U.S. Fish and Wildlife Service 1977). Gas bubble disease probably is not limited to fish. Nebeker (1976) reported that water flea (Daphnia magna), crayfish (Pacifastacus leniiculus), and the stonefly nymphs (Acroneuria californica, A. pacifica, and Pteronarcys californica) were adversely affected by air supersaturation under laboratory conditions. At levels of nitrogen gas ranging from 111 to 125% of normal, signs of gas bubble disease were apparent, including visible emboli and increased buoyancy, depending on the species. Nebeker hypothesized that increased predation, as a result of the stoneflies floating to the surface, could add to the direct gas-induced mortality.

Bell (pers. comm.) stated that, although supersaturation can occur in deep pools of turbulent rivers, it is unlikely that gas bubble disease is a problem in low head hydroelectric projects. It is conceivable, however, that some projects that fall within the definition of SSH (30 MW) can have dams high enough to cause gas bubble disease.

The duration of spillage each year is important in estimating spillway impacts (Bell pers. comm.). Because spillways are designed to pass the maximum expected flood in order to prevent its overtopping the dam, the total yearly spillage volume is determined by the natural seasonal flow pattern at the site and the operation of other impoundments along the stream. If spillage occurs only occasionally, the effects can be minimized by timing the spillage to avoid periods of peak fish use. Higher overall mortalities are likely if spillage occurs over several months each year, even if the spillway design is less injurious to fish than another plant with a shorter period of spillage.

Spillway mortality also involves delayed effects. Spillways increase downstream predation, both from birds and predatory fish, because injured and disoriented fish that have passed over spillways are less capable of escape. Swimming performance of fish is impaired under conditions of extreme turbulence where entrained air lowers the density of the water (Sakowicz and Zarnecki 1954 cited by Dominy 1973).

c. Regional effects. The number of injuries to fish caused by shearing forces, pressure change, striking solid objects, and supersaturated water increases in regions where migrating fish are present. Gas supersaturation affects both migrant and local species of fish that are trapped in areas of supersaturation. Because the probability of gas supersaturation increases with the height of the spillway drop, higher head projects, typical of mountainous regions, are most likely to have this problem. On the other hand, shallow turbulent streams tend to reequilibrate with the air faster than slow moving, deep streams; therefore, mountain streams usually lose any supersaturation much more quickly in tailwaters than do low-land streams. Because each site is different, knowledge of specific circumstances is required.

Spillway impacts are particularly likely to be cumulative in regions where several dams occur in series as they do along the Columbia and Snake

Rivers. Spillway mortalities may account for considerable overall losses in such areas.

d. Trade-offs. Passing more water through turbines may minimize spillage and thereby reduce mortality where spillway related mortality is a significant problem. Conversely, an increase in spillage is sometimes desirable where turbine caused mortality is high, particularly during peak downstream migration.

The higher the dam, the greater the storage capacity at a given site. Increased storage capacity may reduce the need for frequent spillage; however, impoundment effects may increase as a result of reduced spillage (see Section 5.1, Dams and Impoundments). Turbine mortality may increase also, because nearly all fish would go through the turbines. Higher dams require larger spillways, which may lead to increased injury or mortality.

e. Mitigation. The negative effects of spillways can be mitigated by changing spillway design, attempting to keep fish out of the spillways, and controlling the amount and timing of spillage.

5.3 INTAKES

5.3.1 Description

Intakes deliver water through conduits to turbines whereas spillways simply discharge water in order to maintain a desired pool elevation or to prevent water from overtopping the dam.

There are two classes of intakes, low pressure and high pressure (U.S. Fish and Wildlife Service 1977). Low pressure intakes are used for small drawdowns, such as to meet peaking requirements on a daily or weekly cycle, and are located near the surface of the reservoir. High pressure intakes are used for large drawdowns such as to meet seasonal irrigation demands and are located near the bottom of the reservoir. Both classes are designed to achieve specific velocities.

Structures associated with intakes include (Fig. 25):

- The forebay. An enlarged portion of the reservoir adjacent to the intake that has been modified to make the flow uniform prior to entry into the intake.
- Trash racks. Metal grills that prevent debris from entering the intake. The metal bars are usually spaced 6 to 7.5 cm apart for small turbines (Creager and Justin 1950) and up to 15 cm apart for large units. Debris that collects on the trash racks may be removed by mechanical or hand rakes and directed into a trash chute or removed in some other manner. In cold climates, air may be bubbled around the trash racks, or the bars may be heated, to prevent ice from clogging the intake.



Figure 25. View of the trash rack installed at the Cornell University Fall Creek Hydroelectric Plant at Ithaca, New York (H.M. Brundage). Debris is removed from the trash rack by a mechanical rake.

- Screens. Screens may be located inside the trash racks and have much smaller openings designed to keep fish and small debris from going through the turbines. Screens may be fixed or may be rotated to bring collected material periodically or continuously through a washing system to remove debris. Fish collected by the screen, or congregating near it, may be guided toward downstream passage facilities if such diversions are incorporated into the design (see Mitigation Handbook).
- Deflecting devices. Concrete baffles or booms made of logs or steel to divert ice and other debris from the intake. Ice and debris may be shunted to a sluice that discharges on the downstream side of the dam.
- Air inlets. Installed when it is desired to avoid pressures less than atmospheric.
- Intake gates. Devices to control the water flow through the intake. For low pressure intakes, the most commonly used gates include plain sliding gates, wheeled gates, taintor gates, and caterpillar gates. For high pressure intakes, the most commonly used gates include caterpillar gates, cylinder gates, and butterfly valves (see Section 5.2, Spillways). Gates are raised or lowered by various types of cranes, hoists or winches. Small gates may be operated by hand. Multilevel intakes may be located either in the dam or in a tower located near the upstream face of the dam.

The inlet, forebay, and trash racks minimize head loss due to friction; they also reduce turbulent flow and increase velocity. Optimum velocities for energy production are proportional to the head; i.e., low head sites (5 to 8 m) typically have an intake velocity of about 1.5 m/s while velocity for an 18 m head should be a maximum of 2.4 m/s (Creager and Justin 1950).

5.3.2 Engineering and Economic Considerations and Trade-offs

It is generally better to minimize the speed with which water passes into an intake and to have as free a flow as possible in order to alleviate friction (and, therefore, head loss) and entrapment, impingement and entrainment problems. To do this, the intake cross-sectional area must be enlarged or the spacing between trash rack bars increased. Increasing intake cross-sectional area may require construction of structurally complex intake structures. Increasing the spacing between trash rack bars may subject turbine blades or buckets to damage from large debris, increasing engineering complexity, fabrication expenses, and maintenance and replacement costs.

Typically, hydropower dams use intakes that encompass most of the depth of the reservoir at the dam, which means that water withdrawn for the turbines comes from all levels at once. Reservoirs with such intakes usually do not stratify (J. B. Justin pers. comm.). Proposals have been made to retrofit SSH projects to water supply reservoirs. These reservoirs usually have multilevel intakes because they are deeper than many other impoundments and because it may be desirable to be able to choose particular water layers within the reservoir from which to make withdrawals in order to maintain downstream water quality. The multilevel intake for an earthen dam is normally located apart from the dam and is designed to maintain watertight integrity between the intake and the dam (necessary to ensure the structural integrity of the dam). A separate intake can be a complex structure of poured concrete or a simple steel pipe arrangement for a relatively small project. Separate intakes are not needed with concrete dams.

Intake engineering also takes into account other problems, such as icing, turbine type, operating mode of the SSH plant, and environmental requirements. Inlet design can be very important to the survival of fish and other organisms.

Intake costs generally rise parallel to the costs of other project components, although there may be added costs if instream flow maintenance or fish passage is required at all seasons.

5.3.3 Environmental Effects, Trade-offs, and Mitigation

a. Physical and chemical effects. The intake design affects the rate and direction of flow in the reservoir, the depth at which water is removed from the reservoir, and the maximum size of particulate matter, living or dead, that can pass downstream. The location of the intake openings affects both the temperature of the water and its chemical characteristics downstream. The water temperature surrounding deep intakes is likely to be far colder than that of the ambient air or downstream water in most seasons; although the deep outlet often yields somewhat warmer water in the winter than what is present in the river downstream from the dam. Deep water withdrawals may be low in dissolved oxygen and high in ammonia and other undesirable substances (see Section 5.1, Dams and Impoundments).

b. Biological effects. Little literature exists on the impacts of SSH intakes, but a considerable amount of work has been done on the effects of other power plant (nuclear, steam-electric and large scale hydroelectric power plants) cooling water intakes (Boreman 1977; Hocut et al. 1980; American Society of Civil Engineers 1980). The same general principles apply to SSH projects.

The biological effects of intakes can be classified as follows:

- **Concentration.** Organisms gather, are attracted, or drift toward the intakes, usually as a result of induced current field.

- Entrapment. Organisms remain in the vicinity of the intakes as a result of the combination of current flow toward the intake and the dead-end configuration of the intake structure.
- Impingement. Organisms are drawn against the intake trash rack or screen by the force of the current; injury asphyxiation, and descaling may occur from striking or from an inability to move off the screen surface.
- Entrainment. Organisms become trapped in the current flowing toward the turbines and pass through trash racks and the screening into the penstock or turbine. If turbine caused mortality is high, avoiding entrainment by intake controls is important.

The severity of intake impacts is partly a function of the configuration or location of the screening device and of the habits or characteristics of the species present, such as seasonal migratory patterns, depth preferences in relation to time of intake operation, vulnerability, swimming speed, life history stage, size, scale and gill strength, endurance, and whether or not the organisms are likely to feed on debris floating near the screen or on other organisms killed near the inlet. Size and swimming ability, of course, vary with life stage; an organism may be entrained only at certain sizes (ages), impinged or entrapped at a slightly greater size, and able to escape at a still larger size. How long animals are subject to entrainment and/or impingement is both species-specific and dependent on external factors, such as temperature, season, food supply, and crowding, as well as intake operating characteristics. In any case, impingement deaths of smolts migrating downstream are a loss of reproductive potential for a population. Deaths related to entrainment occur during passage through waterways, turbines, and tailwaters. They are also related to predation levels below the dam; many individuals that might otherwise recover from temporary shock become prey for gulls, herons and other birds, as well as large trout, pike or other predators.

Knowledge of the average size and swimming ability of a fish species and the size and shape of the screening material, as well as the average velocity of water through the intake, should enable a prediction of susceptibility of various fish species and age classes to entrainment. This is usually not the case, however, because water velocity at the mouth of the intake may deviate from the average velocity due to obstruction by debris or improper hydraulic design. Although velocity of flow largely determines the intensity of entrainment effects when an intake is open, the total amount of water passed through the intake over time is a better indication of the total entrainment potential, if screening is not effective or sufficient.

The severity of intake impacts on an animal population is also a function of the location of the intake. If the intake is near a natural concentration of organisms (e.g., a wetland or a deep pool with overhanging

shade trees), it is likely to affect more aquatic organisms adversely. The depth of the intake openings can affect the numbers and types of organisms that are at risk. For example, deep water openings tend to entrap organisms that have adapted to higher pressures and lower temperatures than are found downstream. Intake-induced concentrations of organisms may result in competition for food, increased likelihood of disease, and increased predation.

The operating mode of the project (see Chapter 7) may be an important factor determining the degree of exposure of aquatic animals to intake effects. The season of the year also may be a factor, depending on the behavior patterns of organisms in the impoundments. If a dam operates 24 hours per day during the spring, many more downstream migrating fish may be entrapped, impinged or entrained than with the same operation schedule during the summer. A peaking plant (see Section 7.2, Peaking Mode) usually has greater discharge rates than a continuously operating plant (run-of-river, Section 7.1) of the same annual power output. The timing of the power output peaks, relative to the diurnal vertical movement of fish and plankton, largely determines how many organisms are entrained.

Mortality of downstream migrating fish at intakes varies regionally due to the characteristics of the intakes and the local fish species. Regional variation in reservoir characteristics leads to variations in intake type. For example, in mountainous regions, reservoirs are often deep and use multilevel intakes. This increases the possibility of pressure injuries to certain fish species, particularly if coldwater releases are made for the benefit of downstream fish. Such injuries are much less likely in the shallow water reservoirs of the Coastal Plains or Mississippi Valley States because deep water intakes are not used in these areas. A deep reservoir with an irregular shoreline, often found in the Appalachians or Pacific Northwest, usually has a less unidirectional flow toward the intake than a long, shallow river valley reservoir typical of the Midwest.

Species of fish vary in their size, swimming speeds, swimming endurance, avoidance behavior, and body characteristics, all of which influence the degree of injury at intakes. For example, shad are more susceptible to scale loss than salmonids and are affected more by impingement and scraping against rough surfaces.

c. Trade-offs. It is difficult to reduce intake mortality from impingement or entrainment without affecting other environmentally significant factors. For example, if the openings in an intake screening mesh are enlarged to avoid impingement of a certain size fish, the fish may be subjected to turbine mortality or pressure injury in the penstock and tailwater. Similarly, if the intake is closed at night to keep fish out of the turbines, some of the tailwater area will be dewatered and the instream flow necessary for stream organisms below the dam reduced.

d. Mitigation. Mitigative measures for intakes fall into several general categories:

- Keeping velocities low, below 0.15 m/s (U.S. Environmental Protection Agency 1976); U.S. Fish and Wildlife Service 1974 cited by Boreman 1977), to reduce impingement.
- Locating intakes away from areas where organisms naturally congregate.
- Diverting migrating organisms away from the intake.
- Capturing fish at the intake and lifting them over the dam, which also mitigates turbine and waterway mortality.
- Changing the operation schedule to avoid times of day and year when organism susceptibility is greatest.
- Screening to prevent entrance.

5.4 WATERWAYS AND THEIR CONTROLS

5.4.1 Description

Waterways and their controls enable water to pass from the intake within the impoundment through to the turbine and back to the stream. Structures associated with waterways include (Fig. 26):

- Intake gates and valves allow the water flow to be shut off or reduced for maintenance and repairs.
- Conduits include canals, flumes, tunnels, and pipes made from steel, woodstaves, or concrete. Conduits under pressure from a low level intake are called penstocks; conduits not under pressure are called "highline" conduits. Although the primary function of a conduit is to transport water from the intake to the turbines, it may also be used to increase head, especially in the West, where some penstocks are several kilometers long. Long penstocks are used in terrain of high relief throughout the country, wherever an increase in head can be achieved that is sufficient to justify the increased cost of constructing a longer penstock.
- Air valves are required to regulate pressure if penstocks have vertical angles in them. Air outlet valves prevent air from accumulating and causing pipes to become blocked by air; air inlet valves prevent the formation of a vacuum, which could collapse the penstock.

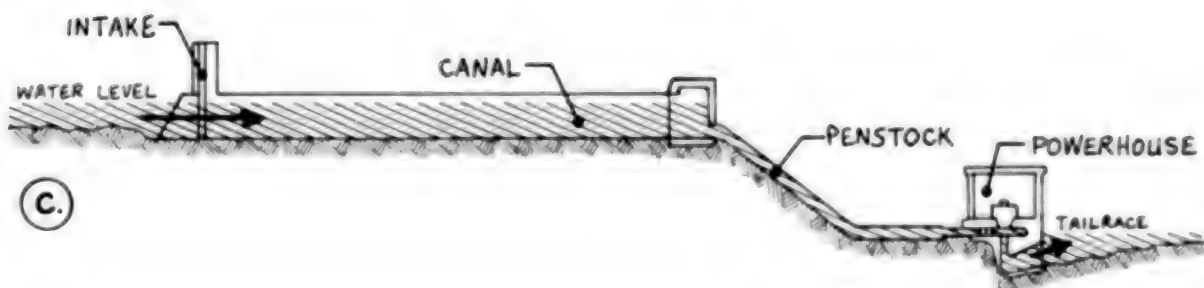
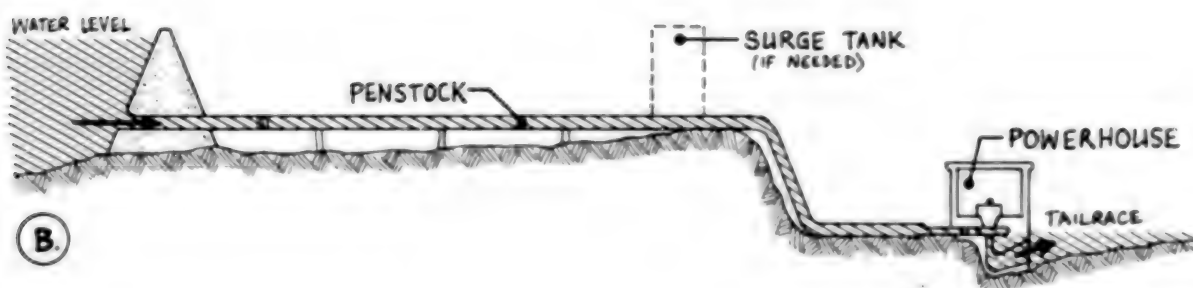
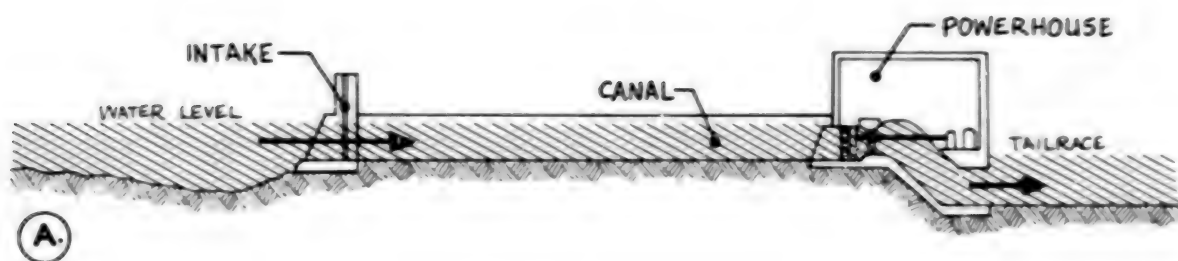


Figure 26. Waterway configurations (American Society of Civil Engineers, Boston Sect. 1980). A. Headrace conduit (free level flow); B. Penstock (flow under pressure); C. Combination headrace and penstock.

- Surge tanks are placed along penstocks and provide a reserve space that dampens the effects of water pressure waves.
- Draft tubes are directly below the turbine. Their primary function is to reduce water velocity gradually from about 7.6 to 9.1 m/s to 1.5 to 1.8 m/s.
- Relief valves allow water to bypass the turbine in order to avoid damage to the turbine by water hammer when the turbine gates are closed and to ensure constant discharge downstream; i.e., to prevent dewatering when the unit is not operating.
- The tailrace provides an avenue for water to be discharged from the draft tube back to the stream. Most tailraces are canals adjacent to the stream channel, although the water may be discharged directly from the powerhouse into the streambed. The tailrace must be deep enough to ensure that the draft tube is always submerged in the tailrace water. A tailrace dam may be necessary to form a pool to ensure that the draft tube is always submerged.
- Tailrace controls include piers, gates, or stops at the draft tube exit that enable the draft tube to be dewatered to permit inspection or repair (Fig. 27).

5.4.2 Engineering and Economic Considerations and Trade-offs

Water pressure is a major factor influencing conduit design and selection of materials from which conduits are constructed. Where pressure is high, welded steel or concrete are most often chosen. These materials have a long life span and freedom from maintenance, but the cost of raw materials and construction can be high. Woodstave pipes are commonly used in the West, particularly in remote areas, because of the ease of transporting woodstaves and assembling pipes up to 5 m in diameter on location. Woodstave pipes are suitable for heads up to 150 m. Maintenance requirements and a relatively short life span (20 to 30 years) are their principal drawbacks.

Extensive rights-of-way and proper gradients are required if canals or flumes are used rather than pipes. Extensive excavation or dredging also may be required. Water velocities must be adequate to prevent sedimentation, but not so high as to cause erosion. Other concerns include water loss by seepage, freezing in cold climates, and dense growths of aquatic weeds in some regions. Canals may be lined or unlined.

Tunnels may be constructed through mountains or large dams, but generally are not cost effective for small-scale hydro projects. Tunnels are commonly used in portions of the Northwest and Alaska where long diversions are necessary and the terrain is rugged.

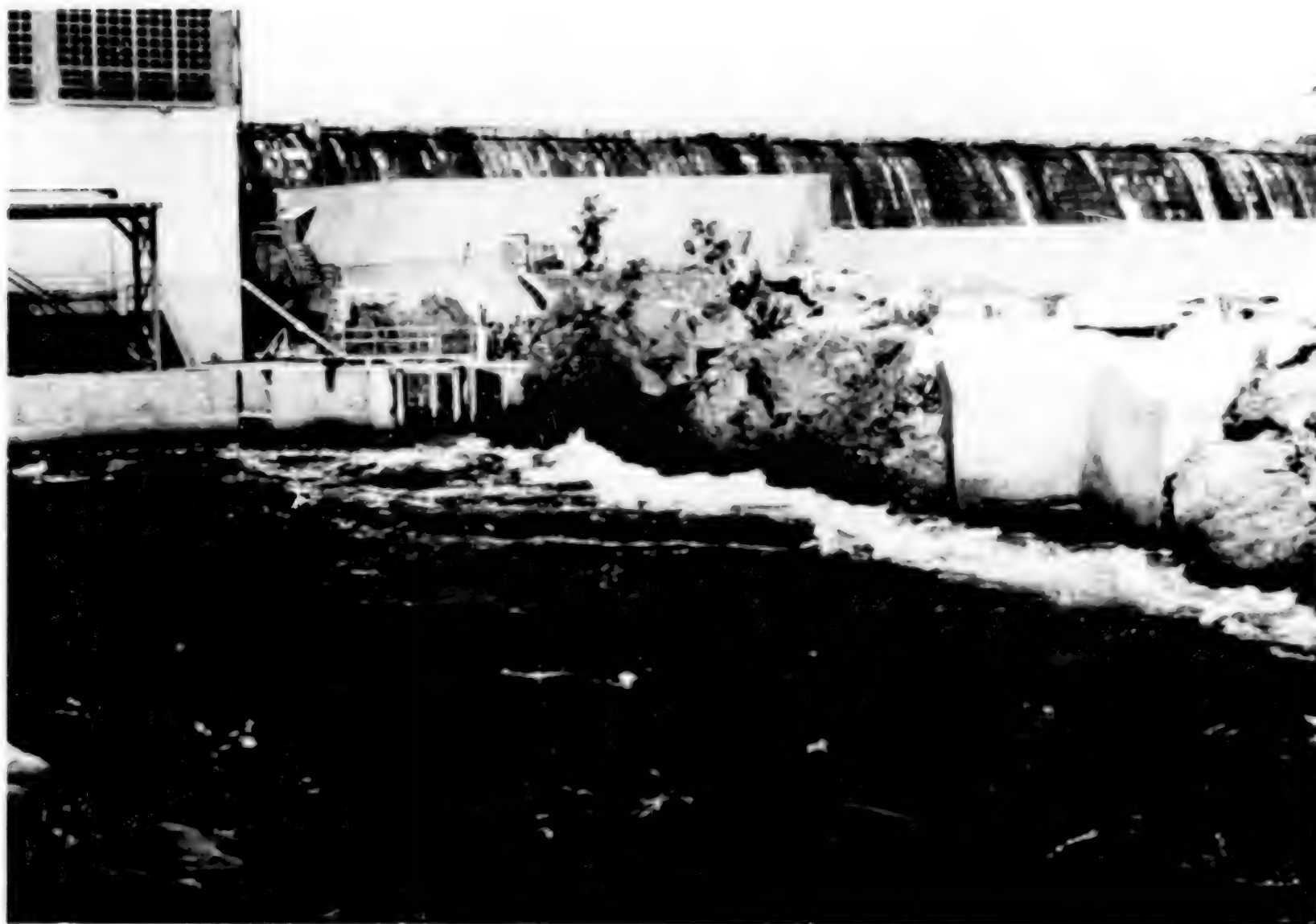


Figure 27. Tailrace of Holyoke Dam, Massachusetts, a 17 MW facility (B. Kynard). Note flashboards at spillway.

Any SSH project provides numerous trade-off possibilities in conduit design. For example, lengthening the distance between the intake and the powerhouse will add head, but project benefits may be offset either by the additional expenses incurred as a result of the increased length and pressures within the pipe (i.e., water hammer and cavitation) or by greater instream flow requirements for the area between the toe of the dam and the end of the tailrace. In designing penstocks, the engineer may opt for high velocity with a resultant small area and commensurately low construction cost. However, doing so increases friction, which results in the loss of some head (Creager and Justin 1950).

5.4.3 Environmental Effects, Trade-offs, and Mitigation

a. Physical effects. Water entering the conduit system is at the ambient pressure for the depth in the impoundment from which it was withdrawn (see Section 5.1, Dams and Impoundments). As water proceeds through the conduit system, there can be significant changes in velocity and pressure. Velocity increases from 1.5 to 2.4 m/s as it passes through the trash racks to 3 to 5 m/s in a penstock. Velocities in headrace canals are usually much less. Maximum velocities in the penstock are attained near the turbine. The amount of shear (difference in velocity between adjacent layers of water in a conduit) is related to the overall velocity of flow and the amount of water in the conduit. Shear is affected only slightly by bends in conduits at the velocities typical for hydroelectric systems (2 to 5 m/s); water velocities are deliberately maintained at low values to minimize friction in the pipe (J. B. Justin pers. comm.)

After passing through the turbine, velocities are reduced in the draft tube. When water exits into the tailwater canal, the pressure returns almost instantaneously to atmospheric pressure (1.033 kg/cm^2). If the turbine is shut off quickly during operation, pressure increases rapidly in the penstock. In extreme cases, water hammer can occur. To eliminate this problem, a surge tank may be used or water flow into the turbine shut off slowly using control gates. Restarting a turbine creates suction that momentarily lowers penstock pressure until flow equilibrium is reached.

b. Biological effects. Maintenance of downstream flows is a major environmental issue. Water diversions for power generation may reduce or even eliminate flow in the natural stream, causing a serious problem for both upstream and downstream fish passage. Flows in the by passed reach below the toe of the dam may be limited to the amount of water that seeps under or through the dam or is provided by either a tributary stream or ground water (Fig. 28). The length of the affected reach depends on the length of the waterway, up to several kilometers in extreme cases. Sometimes only part of the original stream flow goes into the penstock (e.g., in some diversions in the West), but the remaining streambed is still significantly dewatered, with resulting sediment accumulation, stagnant pools, and thermal effects when discontinuous shallow reaches are heated by the sun. If the waterway is very long or if a meander is bypassed (Fig. 29), significant aquatic habitat area can be lost. Habitat loss in associated riparian wetlands may be much greater than the length of the waterway; it is rarely less.



Figure 28. Dewatered section of the Connecticut River below the Holyoke Dam, Massachusetts (B. Kynard).

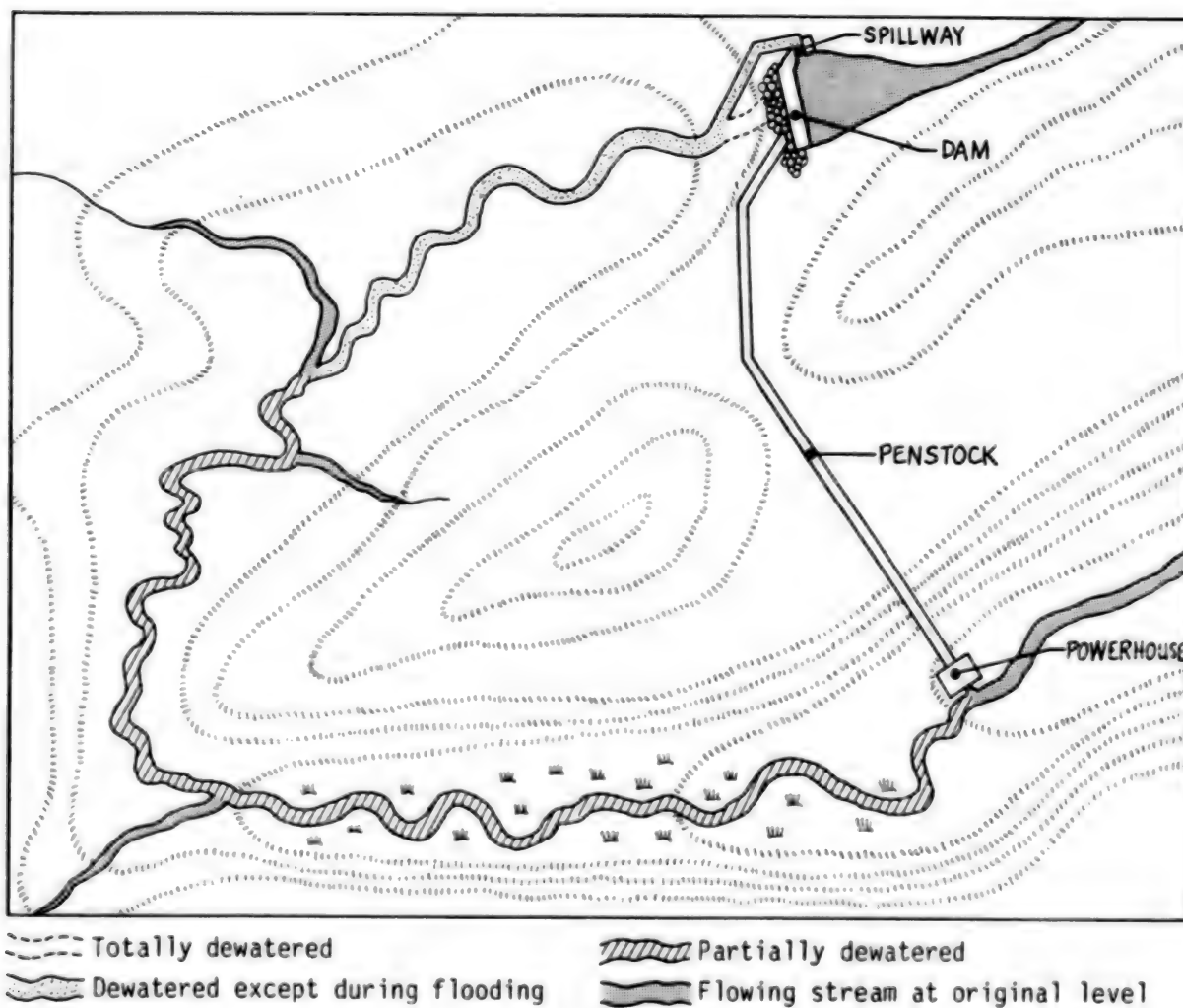


Figure 29. Example of a stream diversion for a small-scale hydro project illustrating the potential reduction in high quality stream habitat (T. Lloyd Associates).

Open waterways (e.g., open flumes and canals) are typically shallow, with smooth, clean bottoms. Fish passing through them may be subject to increased predation and disease. Fish trapped in a canal for an extended period by a system shutdown may be unable to find sufficient food because of crowding and limited habitat diversity. For wildlife, the open canals, which often have steep sides, present a hazard. A canal leading to a penstock sometimes presents a blind trap for animals that follow the canal downstream and then cannot escape because of steep sides near the penstock inlet.

The effects of high pressures in closed waterways, or penstocks, on fingerling salmon have been shown in U.S. Army Corps of Engineers (1960) tests. It was found that fish subjected to high pressures in a closed water-filled vessel are relatively unharmed when the pressure slowly returns to the original level. However, if the vessel contains air and the fish become accustomed to the higher pressure, they may be killed during rapid decompression. Under test conditions, only decompressions which occurred in a fraction of a second produced heavy mortality. The results of these tests are shown in Table 6. More fish died when subjected to the greatest pressure drop. Such a pressure drop can develop in a SSH project if fish from a deep layer are placed in a penstock and then spilled out into a shallow tailwater. It is unlikely, however, that the pressure gradient would be as steep as the maximum in the above tests.

Table 6. Pressure effects on salmonid fingerling mortality (U.S. Army Corps of Engineers 1960).

Pressure range in 3.3 m length of pipe (kg/cm ²)	Number of fish passed	Number of immediate fish deaths	Number (and %) of deaths after 1 week in live boxes
1.31-0.53 (2 tests)	200	1	1 (0.5)
1.39-0.28 (2 tests)	200	3	3 (1.5)
2.19-0.04 (6 tests)	600	27	47 (7.8)

When fingerling salmon were discharged under tailwater conditions in one experiment in the Corps' study, the fish confined to a 210 liter barrel were quickly killed when a stream of water at 7.03 kg/cm² was directed into the barrel (U.S. Army Corps of Engineers 1960).

In a second discharge experiment, which may approximate the conditions that occur when fish encounter energy dissipation valves used in a turbine bypass, fingerling salmon were released at a velocity of 13.9 m/s, into a 30-cm jet of water at either a 45° or a 90° angle against a steel plate. Fish experienced a pressure drop from 2.25 kg/cm² to atmospheric pressure (about 1.03 kg/cm²). The fish hit the steel plate almost immediately after exiting the pipe. The results are shown in Table 7.

Table 7. Effect of physical impact on salmonid fingerling mortality (U.S. Army Corps of Engineers 1960).

Impact angle	Number of fish	Number of fish killed immediately	Total fish (and %) killed after a 7-day holding period
45°	1000	4	17 (1.7)
90°	1000	7	33 (3.0)

Long waterways specifically for hydroelectric projects are typically found in mountainous regions. They create dewatered zones immediately below dams or elsewhere, depending on the exact project configuration. Although salmonids are quite resistant to injury from pressure and turbulence, they cannot withstand substantial losses of coolwater stream habitat. Such a loss may happen, for instance, in the Rocky Mountain States, where long diversions of up to several kilometers are common. In the East and Plains States, penstocks are usually shorter; even so, a dewatered reach of any length can disrupt fish passage. Even if a spillway empties into this reach, spillways normally operate only under seasonal high water conditions, leaving the dewatered area unsupplied for most of the year.

c. Trade-offs. There are many potential trade-offs related to lengths of open and closed (pressurized) waterways necessary to gain a given head; however, in most instances the choice between penstock versus canal is predetermined by existing facilities or individual site characteristics. For example, if a structure exists (such as an abandoned millrace) that could supply the water needed and that could be restored economically, it is unlikely that a new intake and penstock would be constructed at the dam. Figure 30 illustrates another potential trade-off. In the first instance (Project A), the needed head could be provided by the combination

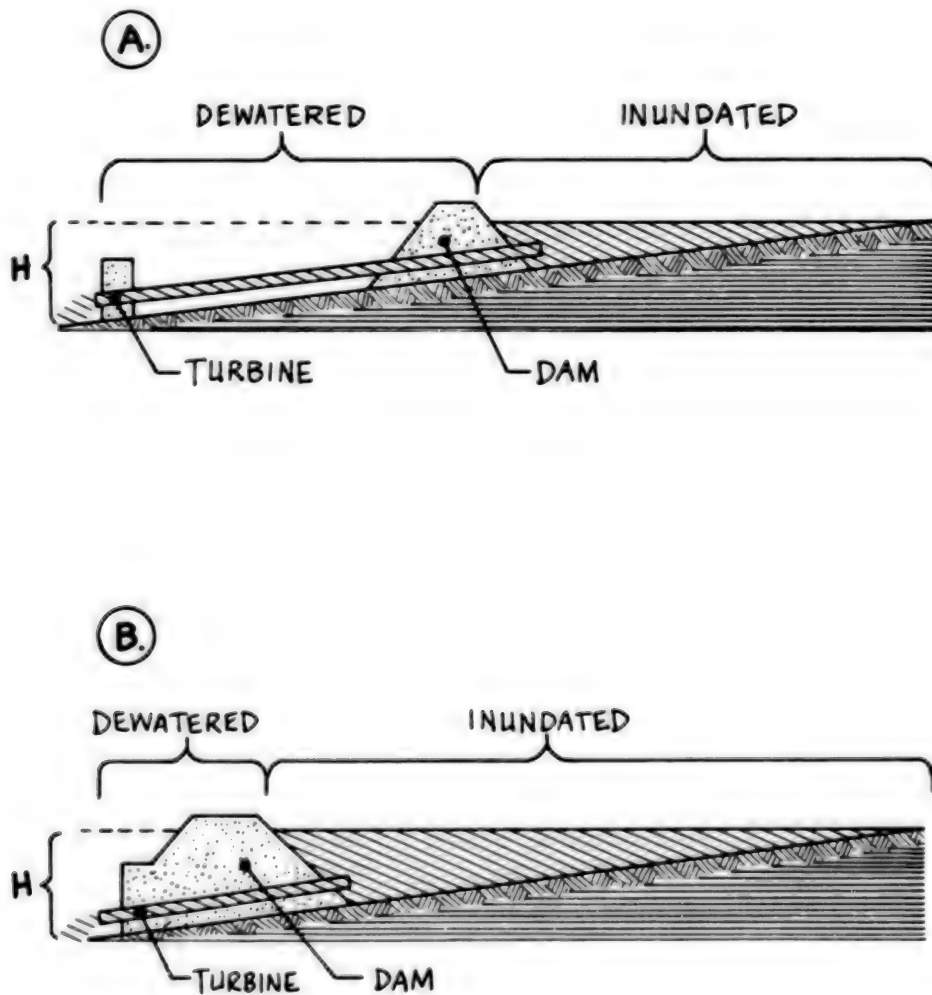


Figure 30. Two hydro projects on the same slope yielding the same head (T. Lloyd Associates). Project A, with the lower dam and remote powerhouse, has a much longer dewatered area than project B.

of a low dam and long diversion. In Project B, the same head is achieved without any diversion but by building a higher dam. It must be recognized, however, that economic factors such as the increased cost to construct the Project B dam and increased cost to acquire land that would be flooded probably would make Project B unfeasible.

Pressure change problems are more frequent in plants subject to frequent start-ups and shut-downs, such as peaking plants. Peaking creates a greater problem in this respect than run-of-river or seasonal base-load (storage) plants with the same waterway configuration. It may not be possible to choose the mode of operation, however, because site conditions or local economic conditions may indicate that only one operating mode will succeed.

d. Mitigation. Mitigation measures for waterways consist mainly of finding ways to ensure passage around the dewatered zone, either by maintaining instream flow or by providing a separate passage canal. Keeping fish out in the first place is the most practical mitigation for injuries that occur within the conduits leading to turbines. Therefore, this is an inlet problem, not a waterway problem (see Mitigation Handbook).

5.5 POWERHOUSE AND AUXILIARY EQUIPMENT

5.5.1 Description

The powerhouse contains the hydraulic and electrical equipment of a hydroelectric facility. Associated structures may include a secure area for transformers, circuit breakers, and other transmission equipment not contained in the powerhouse, buildings to store spare parts and maintenance equipment, and parking facilities. The powerhouse may be an integral part of the dam or located apart from it. If it is separate, the land required may range from 50 to more than 300 m² (U.S. Army Corps of Engineers 1979), not including parking and other facilities. Some of the more important equipment found in the powerhouse includes the following (U.S. Fish and Wildlife Service 1977):

<u>Equipment</u>	<u>Purpose</u>
Flumes and scroll cases	Deliver water to the turbines and distribute it smoothly and at the desired velocity.
Turbines	Convert potential energy of water into mechanical energy.
Governors	Regulate turbine speed within a desired range by increasing or decreasing the amount of water supplied to the turbine runner.
Generators	Convert mechanical energy to electrical energy.

Transformers	Step up voltage from the generator level to the transmission level.
Main control board	Enables the operator to monitor and control all plant functions, including voltage levels, current levels, watts, temperature, and turbine speed.
Synchronization and voltage regulation	Ensures that the generator is synchronized in order to achieve proper frequency; voltage regulation ensures consistent output at the required level.
Generator breakers and line breakers	Connect the generator to the power grid. The generator breaker closes when the unit is synchronized with the power grid and disconnects if the unit malfunctions.

Manpower requirements to operate the intakes, spillways, and powerhouse are variable, but typical SSH projects require no full time operators. Many facilities are operated automatically and only need to be inspected 1 day per week for routine maintenance and upkeep.

Major components of the transmission system include transmission lines, supporting towers (Fig. 31), and substations. Power is conducted through copper or aluminum cable with a steel core. Porcelain insulators suspended from transmission towers keep the wires isolated from the ground and prevent short circuits.

Substations transfer power between circuits, transform power from one voltage to another, and monitor the system. Their primary purpose is to increase or reduce voltage of bulk power supplies to power consumers. Substations ordinarily include transformers, voltage regulators, switches, and protective devices.

5.5.2 Engineering and Economic Considerations and Trade-offs

The powerhouse and switchyard should be close together to minimize low voltage power losses. The location and capacity of transmission lines are typically dictated by the power output of the site and other considerations, such as the availability of rights-of-way, the ruggedness of the terrain, and the location of the intertie to the power grid. As a first choice, the shortest possible route is taken. If the distances between transmission towers are long, the towers must be taller because the sag of the lines must be kept a minimum distance above the ground. Transmission lines with shorter spans can use shorter towers, but usually require more of them. Lines cannot be too close to any object because of possible flashover (arcing); they require greater separation as the voltages increase.

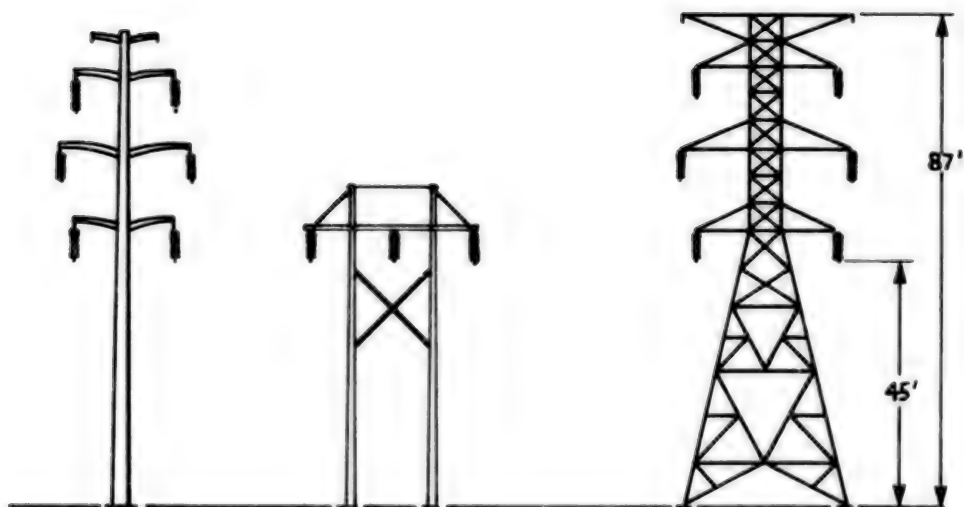


Figure 31. Conventional transmission tower designs (U.S. Fish and Wildlife Service 1977). A. Pole; B. H-frame; C. Lattice.

Transmission lines often require a large amount of land (Table 8). Space must be allowed both horizontally and vertically, unless the line is buried (often very expensive and normally used only in urban environments). Trees and structures, even those not directly under the lines, may need to be removed or cut back as a precautionary measure. Deviations from a generally straight path from the power plant to the intertie with the electrical grid system are costly, and developers usually avoid them whenever possible (Galvin 1979).

Table 8. Space requirements for transmission lines (Galvin 1979; Thompson 1978). Higher towers require more right-of-way width because sagging lines must be allowed to swing, and ground clearance cannot be decreased below a minimum. Because of sag in the wires, if smaller towers are used, more are required to keep the line above minimum clearance levels. Typical amounts are 3 or 4 towers per kilometer.

Voltage (kV)	15	69	115	16	230	500
Ground clearance in meters (minimum)	6.7	7.3	7.6-8.2	8.2-8.8	9.1-9.4	10.7
Right-of-way widths in meters (typical)	-	-	27-47	-	30-46	41-61
Right-of-way area in ha/km (typical)	-	-	2.8-4.5	-	3.0-4.5	4.0-6.0

Another economic consideration is whether or not to use a manned powerhouse. It is generally less expensive to use an unmanned powerhouse; indeed, small-scale hydro projects often have no powerhouse at all and rely on weather-resistant equipment instead. The saving in construction costs and complexity of an unmanned powerhouse is balanced against decreased security, slower response to some emergencies, and service inconvenience for turbines or generators in bad weather. Nonetheless, most plants built today have neither an operator nor a powerhouse.

5.5.3 Environmental Effects, Trade-offs, and Mitigation

a. Physical and chemical effects. The main physical impacts of the powerhouse and auxiliary equipment are that they can be a barrier to animal movement. Many areas are fenced, paved, or maintained in a bare soil condition. This can result in reduction in wildlife habitat, increased stormwater runoff, and increased contamination of streams, particularly with fine sediment. In some instances, powerhouses are located in former stream channels that have been filled to accommodate the structure. This may affect streamflow and certainly eliminates aquatic habitat.

Other physical effects include noise from equipment, workers, and vehicles; some equipment emits an electrical hum that may be distracting to animals. Electrical energy (corona) emitted from transmission lines has electrocuted birds (U.S. Fish and Wildlife Service 1977). The power plant and its vicinity are often lighted at night for security or other reasons; these are frequently the only lights in remote locations. Lights at night may disorient birds and animals.

Chemical impacts near the powerhouse site are normally minimal, although waste oil, unused pesticides, paint and thinner, and human waste may pollute streams. The main chemical effect of the powerhouse and auxiliary equipment is usually a result of the use of herbicides and fertilizers for the maintenance of transmission line rights-of-way and grounds at plant sites (see Section 7.4).

b. Biological effects. The effects of SSH powerhouses and their associated equipment on fish and wildlife range from negligible, in the case of urban pipe network systems, to potentially very severe for remote rural systems.

The powerhouse, transformers, and associated equipment may take a few tens of square meters for small projects up to about 2 ha for large ones. This land use eliminates habitat for plants and animals. Power plant development invariably requires land clearing; riparian vegetation is most often affected. If the powerhouse site is in a cultivated area, it is likely that effects will be minimized because such a site needs little adaptation to power plant use. In contrast, a southern riverine hardwood swamp or a mountain spruce-fir forest requires considerable modification to become suitable as a powerhouse site.

Access must be provided to the SSH facility for service monitoring. However, opening a road to the plant also allows other people (hunters, fisherman, hikers, and off-road vehicle and snow-mobile enthusiasts) to reach the site. Increased site use usually has little effect in an already populated area. The use of remote sites is likely to increase substantially, however, and such use can disturb animals, increase mortality, cause injury, and increase the risk of fire.

The powerplant site may have beneficial effects for wildlife (Leedy et al. 1980). Urban power plants often provide sites that are landscaped,

fenced, and comparatively undisturbed. They may provide stopover locations for small birds and shelter for small mammals. Power developers sometimes provide boat access and waterway security, trash clean-up, and road maintenance that permit visitors to use the impoundment water with less habitat damage than would occur if no limitations on access existed.

Transmission lines potentially have both positive and negative impacts. The magnitude of the impacts is directly related to the width of the right-of-way area and the length, height, and location of the line (route). The tower height determines the number of towers required and may affect both habitat diversity along the route and the severity of construction impacts (see Chapter 4).

Installation of a power line sometimes substantially changes biological communities. The line must be kept clear of trees in order to avoid flashover and to allow servicing. Clearing alters the plant community both within the right-of-way, and in the adjacent area. For example, when dense tree stands are opened up by clearcutting a right-of-way through a forest, shade-tolerant species are replaced by sun-loving species. Although the individual species may change over time, the power line plant community must be permanently maintained in a grass or old-field stage, unless it is naturally clear of tall vegetation (e.g., a desert or marsh). Nonnative grasses and legumes may be planted as cover crops on power line rights-of-way, leading to further changes in vegetation and wildlife communities. In some instances, power line corridors can increase the variety of habitat. For example, when lines run through cultivated fields, a permanent shrub-grass "island" is created at each tower sight that may provide refuge and a food supply to birds, rodents, insects, and other small animals. When a transmission corridor runs through a mature forest, species, such as deer, that utilize an "edge" habitat may benefit. Cleared right-of-way is much more accessible to visitors, with or without vehicles, than a mature forest; hunting, fires, and other visitor effects usually increase when lines are put in.

The transmission lines present a particular hazard to birds (Avery 1978, Avery et al. 1980), although some birds nest successfully in transmission towers, especially in areas where trees are scarce. Transmission lines also are used as perches by raptors (Miller et al. 1975).

Most SSH projects have fewer wires and shorter transmission corridors than larger projects. However, two properties of SSH development can make its effects significant to wildlife:

- SSH is necessarily closely associated with water where birds and wildlife are likely to gather. This can increase their contact with power plants and transmission lines.
- Some plants are built in remote areas, where transmission corridors must necessarily be long and the impacts more severe than in urbanized areas.

The extent of power line hazards to birds depends on the location and length of transmission lines added when the SSH project is installed, the species and numbers of birds in the area, and several characteristics of the lines themselves (Avery 1978). Birds fly in certain pathways between nest sites and feeding or cover areas. If the power lines cross one of these pathways, the probability of injury or mortality increases. Lines crossing rivers are particularly hazardous because birds often fly low along the river axis. When towers cross the path of a prevailing wind, such as through a valley notch or up a slope, birds may follow the wind into the lines.

Line characteristics are also important. When towers are higher than surrounding objects, birds migrating through the area may collide with them, particularly if the weather is poor and visibility low. Smaller lines on these towers are particularly hazardous; birds often avoid the main power line, but strike the static (ground) wire, a thin wire running along the very tops of the transmission towers to protect them against lightning. Wires arrayed on a single level (horizontal arrays) seem to be less hazardous to birds in most cases than multiple level arrays. Small diameter, low wires in dense patterns seem to result in the greatest mortality for birds making local flights.

The number of birds killed by contact with transmission lines may be small compared to the number killed by hunting, predation, or even starvation. On the other hand, if the mortality is in populations of rare or endangered species, the losses are more serious.

In the Northeast, Upper Midwest, and Ohio River Valley, the power line network is already very dense. SSH project development usually causes little increase in the power line network because existing lines can be used. Similarly, many powerhouse sites in the East have been cleared for many years and do not require additional land clearing or wetland filling. The longest transmission corridors are located in the Pacific Northwest and Alaska, where many SSH projects are remote from urban areas.

Other regional considerations involve waterfowl migration routes, which are concentrated where streams are associated with wetlands, such as in the Northern Midwest and central valleys of Oregon, Washington and California.

c. Trade-offs. The powerhouse and transmission lines are essential to any hydroelectric development, and their real extent is dictated by the power output of the site. The main trade-off possibilities involve alternative locations to minimize impact. A downstream powerhouse usually keeps powerlines away from reservoirs, but lengthens the dewatered zone below the dam (see Section 5.4, Waterways and their Controls). Keeping transmission lines away from high ground may reduce soaring bird collisions, but increase the losses of waterfowl.

Alternative locations for the powerhouse and transmission lines usually require more land because initial engineering and economic objectives generally minimize the cost and complexity of the projects. Therefore, benefits of alternative locations may be counterbalanced by possible greater overall habitat loss.

d. Mitigation. The effects of powerhouses and auxiliary equipment can be minimized by limiting the amount of land used. Animals sensitive to disturbance can be isolated from project impacts by installing physical barriers around equipment, choosing locations that avoid animal routes, and using designs that encourage animals to avoid dangerous areas. Security measures can keep visitors away from critical or important animal habitats.

Mitigation for power line corridors can include planting vegetation attractive to desirable wildlife, optimum routing to minimize direct and indirect impacts, limiting the use of herbicides and other toxic substances for construction and maintenance, and controlling public access. Refer to the Mitigation Handbook for more details.

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6. TURBINE-RELATED IMPACTS

Turbines convert the potential energy of water (head) into mechanical energy. Turbines may be designed to exploit pressure differences between water masses or to capture the kinetic energy of water in motion or to use a combination of both pressure and velocity. Turbines are the modern equivalent of the waterwheel, but are superior for generating electricity because they have higher rotation speeds, are less bulky in relation to their power output, and are more efficient in capturing the power of falling water.

A turbine has four main parts, which take a wide variety of forms, depending on the turbine design and the installation method (Fig. 32). First, there is an inlet, to direct the flow toward the second part, the runner. The runner is a wheel of many buckets or blades of various sizes, shapes, and numbers, depending on turbine design. In some turbine designs, the runner is tightly enclosed in a casing or pipe and is, therefore, totally immersed in water; other installations have the turbine at least partially surrounded by air at atmospheric pressure. The third part of the turbine is the outlet, or draft tube, which carries the water away from the runner into the tailwater. The fourth component, present in all but the smallest turbines, is a control mechanism, which may include a speed measuring device, governor, valve or gate adjustment devices in the inlet, air inlets, and lubricating and turbine blade adjustment mechanisms.

Despite the advantages of modern hydroelectric turbines, they have various environmental effects, of which the most important is the killing of fish moving downstream. Fish that are sucked or swim into the turbine may be subjected to a number of life-threatening situations within the turbine, depending on the design and operation characteristics of the particular turbine involved. Some of the more important of these variables are the width of the most constricted portion of the flow pathway through the turbine, the shape of the interior of the turbine and the extent of the chopping action of the blades, possible extreme turbulence or pressure changes that may be produced in some designs, and the operating efficiency of the turbine. Additional important considerations are the amount of clearance between the blades of the turbine, the clearance between the blades and the casing (blade enclosure), and whether the turbine is oriented vertically or horizontally.

Efficiency is a particularly important concept for the engineer selecting a turbine and, since efficiency is a factor in turbine mortality, it is also a concern of the biologist. Efficiency is the ratio

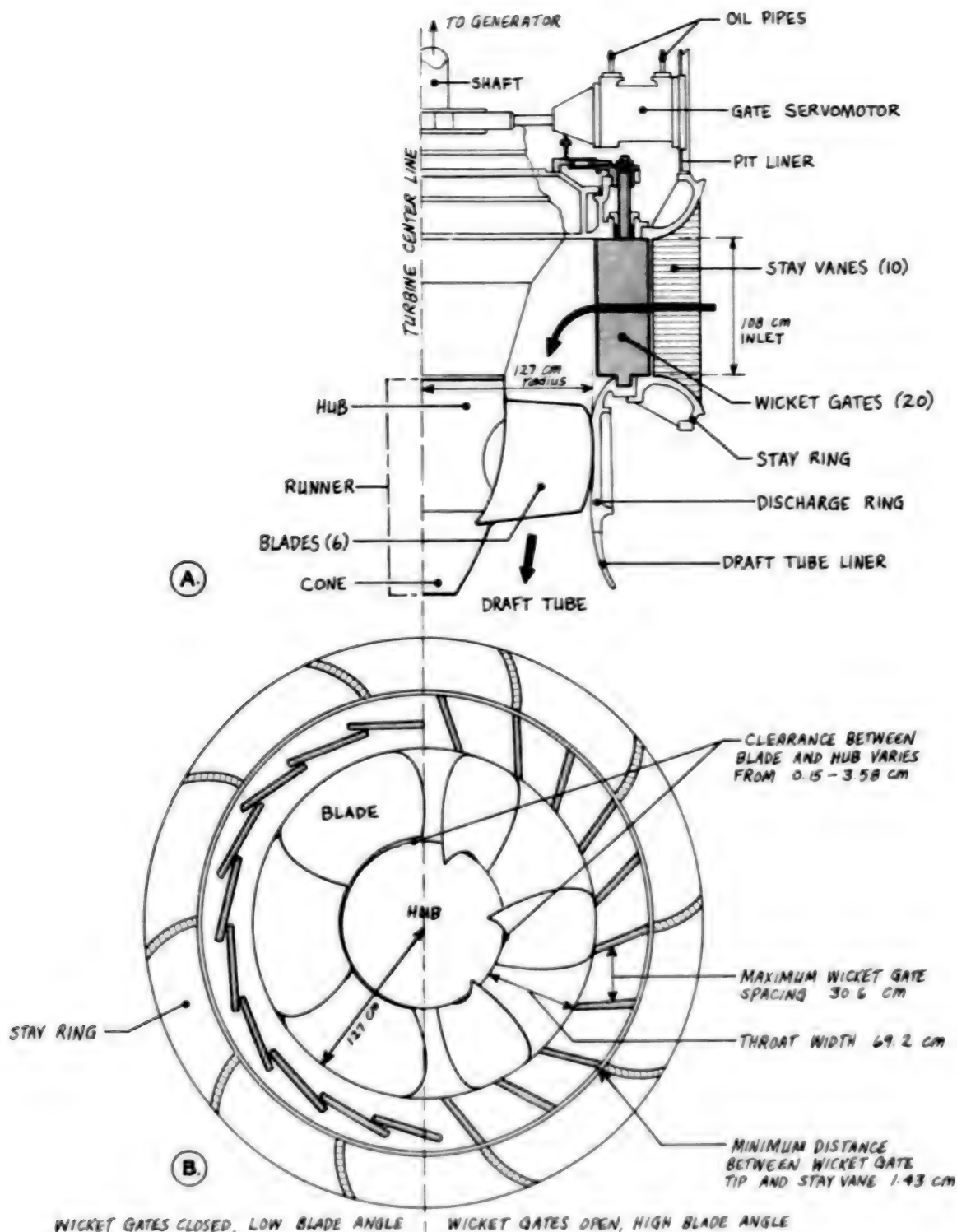


Figure 32. Components of a 13,800 hp (about 10 MW) vertical Kaplan turbine (Scott 1981). A. The turbine in a longitudinal half-section, showing its major parts; B. Diagrammatic cross-section showing changes in flow passage clearances between closed and open positions.

of the power delivered by a turbine to the power supplied to it by the water. For example, if the water entering the turbine has 8,000 kW of power and 7,000 kW are delivered to the generator shaft by the turbine, the efficiency of the turbine is $7000/8000 = 87.6\%$. Maximum turbine efficiencies of 90 to 92% are common for most types of turbines when they are operating at design loading (Creager and Justin 1950). When the actual load falls below 25% of the design load, the efficiency usually declines rapidly, depending on the type of turbine used and the state of its maintenance. Efficiency curves are available from manufacturers or in engineering texts for each particular turbine type. Other factors that significantly influence turbine operating efficiency are cavitation, setting, and sigma (σ).

Cavitation is the formation of partial vacuums in a flowing liquid due to the separation of its parts. This is followed by violent activity at another point some distance along the flow path when the bubbles of vapor collapse as the pressure increases. Pressures up to $9,000 \text{ kg/cm}^2$ may occur. Extreme cavitation reduces turbine efficiency and may cause serious damage to the turbine (Creager and Justin 1950; Scott 1981).

Setting refers to the distance that the runner is set away from the tailwater (Creager and Justin 1950). The setting of the turbine is important because the correct setting can increase power, improve efficiency, and reduce cavitation. In general, the setting must be made deeper as the head increases in order to equalize pressure above and below the runner, but a deeper setting requires greater excavation costs.

Sigma (σ) is a number used to specify the depth of turbine setting necessary to avoid cavitation; it is also important in predicting fish survival. Technically, it is a positive, dimensionless number expressing the point, in relation to total head, at which the "underpressure" below the blade should not be exceeded (Bell et al. 1967).

The following discussion of turbines and their impacts is divided into two sections: conventional turbines and unconventional turbines. Each section contains the following information: a description of each type of turbine with particular attention given to factors affecting fish survival (efficiency, size of openings and hydrodynamics resulting in cavitation or pressure buildups); engineering and economic considerations and trade-offs; environmental effects, including physical, chemical, and biological impacts; environmental trade-off possibilities; and mitigative measures.

6.1 CONVENTIONAL TURBINES

6.1.1 Purpose

Hydropower turbines can be classified into two main groups: tangential or impulse turbines and reaction turbines. Impulse turbines capture the energy of a high velocity jet at atmospheric pressure on relatively small buckets or blades on a wheel (Russell 1954 cited by Ruggles et al.

1981). Reaction turbines are completely flooded with water under pressure while in operation and obtain energy both from pressure differences between upstream and downstream sides of the blades and from the force (kinetic energy) of the water moving through the runner. Both types of turbines have been used effectively in SSH projects.

The main conventional turbines that are used in SSH projects are:

Impulse turbines

Pelton Wheel
Turgo Impulse™ wheel
Cross-flow (Ossberger, Banki-Michell)

Reaction turbines

- Mixed flow
- Francis
- Samson

Axial flow (Propeller)

- Kaplan
- Tubular
- Bulb
- Rim (Straflow™)
- Hydrolec™ turbine/generator

a. Impulse turbines. Impulse turbines have air at atmospheric pressure inside the turbine enclosure; nozzles or guide vanes restrain the pressure and release the water as needed to make the kinetic energy available to the runner. The Pelton and Turgo Impulse™ wheels (Fig. 33) use a needle valve for the precise regulation of the water flow. The Pelton runner consists of a series of buckets on an open wheel; from 1 to 6 nozzles direct a stream of high velocity water toward the buckets to turn the wheel. The Turgo Impulse™ wheel acts in a similar way, but the buckets are on only one side of the wheel. The engineering advantage of the Turgo Impulse™ wheel is that it uses a bigger water jet; therefore, the wheel spins at a higher speed for the same head and power output as a comparable Pelton wheel.

For cross-flow impulse turbines (Fig. 34A) the water is regulated by guide vanes rather than nozzles. The runner of the turbine is essentially a hollow cylinder, the sides of which are a series of long curved blades. Water is distributed along the surface of the runner by the guide vanes; it enters on one side of the cylindrical runner, flows toward the center of the runner, and then flows out the other side (Fig. 34B) The cross-flow design is unique in that the water passes through the blades twice, which means that entrained organisms are subjected to possible strikes by the blades twice.

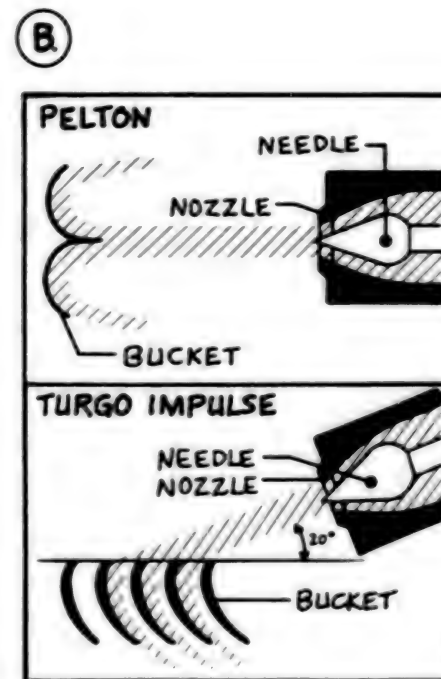
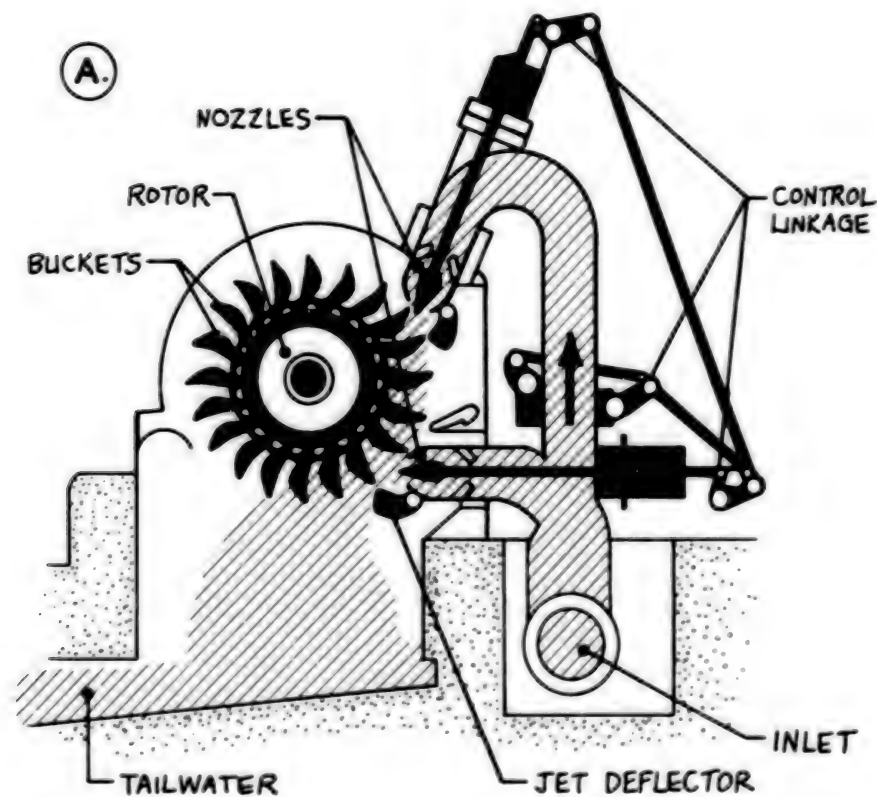


Figure 33. Impulse turbines, I (Heutter 1978; Gilbert, Gilkes and Gordon Ltd.). A. Two-nozzle Pelton turbine; B. Patterns of water flow from nozzle through buckets of Pelton and Turgo Impulse™ runners.

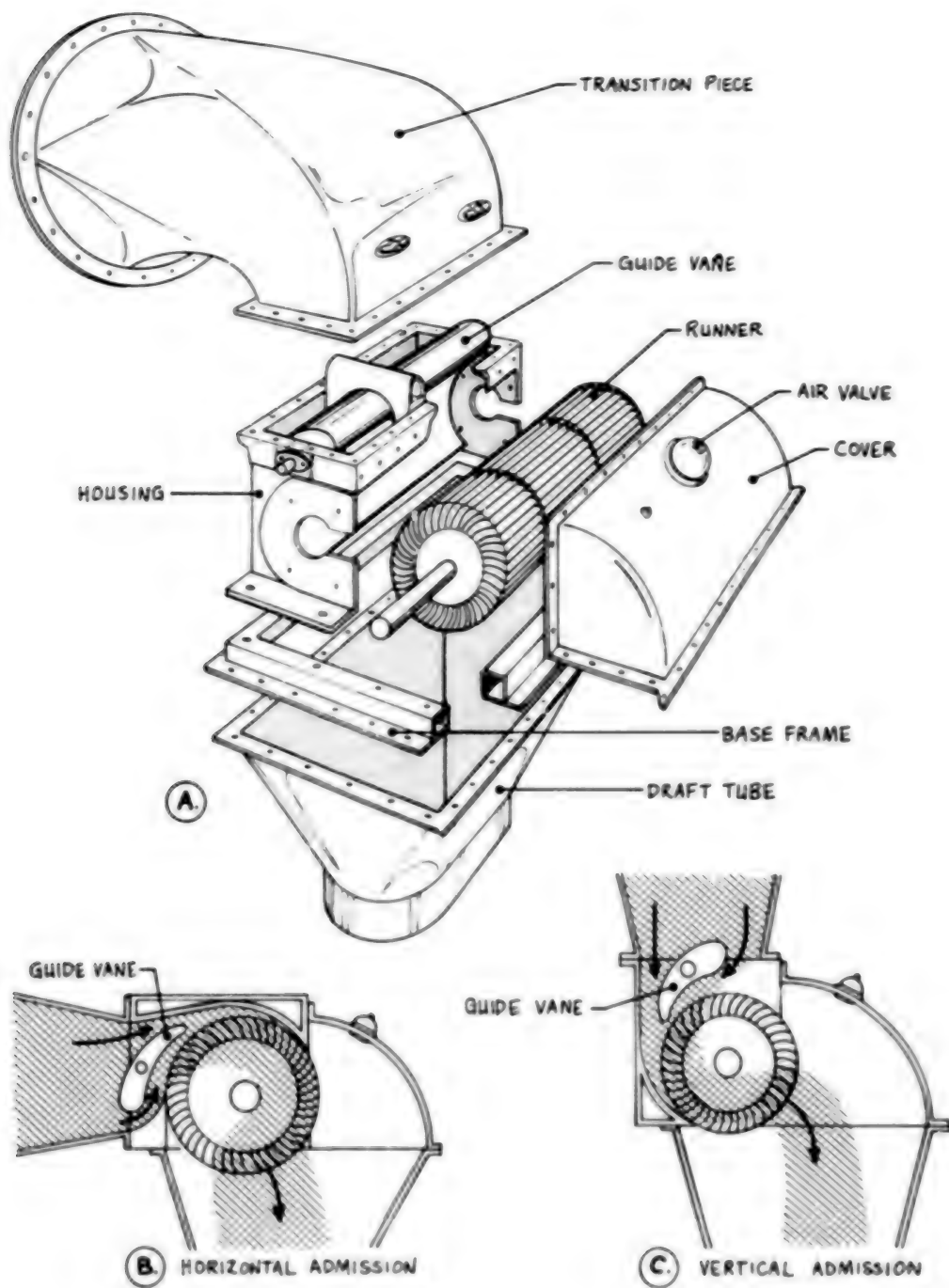


Figure 34. Impulse turbines, II (Wayne 1980). Cross-flow. A. Typical Ossberger turbine assembly in exploded view; B.,C. Patterns of flow through cross-turbine.

Cross-flow turbines operate at high efficiency over a wider range of heads and with more widely varying flows at any given site than common impulse or reaction turbines. However, commercially available cross-flow turbines are limited to a 1250 mm maximum diameter, so multiple turbines may be required at a particular site (Pruce 1980).

b. Reaction turbines. Reaction turbines in common use are of two main types, Francis and Propeller. Francis turbines are mixed flow devices; that is, the overall direction of water flow is changed during passage across the runner blades by about 90° from its entry direction (Fig. 35). Water surrounding the runner enters through a ring of guide (stay) vanes. A ring of wicket gates, positioned just inside the guide vanes, adjusts the flow, and can be completely closed if necessary to stop the runner. The turbine may be submerged in an open flume or surrounded by water in a spiral case. The Francis runner is an old design that has had extremely wide use in the United States. Some small units with the Francis type of runner have also been called Samson turbines.

In propeller turbines, the water flow is axial, or straight through along the runner axis. Propeller turbines are classified as either movable blade (Kaplan) or fixed blade.

The Kaplan turbine (Fig. 36) has an adjustable propeller that may be oriented either vertically or horizontally. It operates with water surrounding the wicket gates in a spiral case; water passing through the wicket gates flows past the propeller in an axial flow. The wicket gates can be adjusted to regulate the flow, and the propeller blades are movable to achieve maximal efficiency at any given flow (Fig. 36A). Thus, the Kaplan turbine can maintain a very high operating efficiency over a wide range of flows. In the vertical configuration, some sort of concrete casing or metal scroll case is required to direct the water evenly around the runner. In order to prevent cavitation, however, a deep draft tube (outlet) must be used, which requires excavation, making the Kaplan in a vertical orientation relatively expensive to install.

Tubular turbines (Fig. 36B and 36C) use a horizontal or inclined casing with the propeller runner located inside. The power shaft passes through the casing to the generator, in either an inclined direction or horizontally, in line with the axis of rotation of the runner, where its energy is converted to electrical energy. Because tubular turbines use a prefabricated casing, they are often much less expensive to install than custom-designed propeller turbines and casings. Tubular turbines have less head loss in the casing than Kaplan or Francis turbines. Tubular turbines also generally have faster speeds of rotation than comparable Kaplans and frequently utilize speed increasers which reduce the size and cost of generating equipment and, consequently, the cost of the structure to house this equipment. Tubular turbines often have adjustable propellers, which are sometimes called semi-Kaplan runners. Current practice is to include adjustable guide vanes on many tubular turbines, thus providing the equivalent of full Kaplan efficiency and flow range.

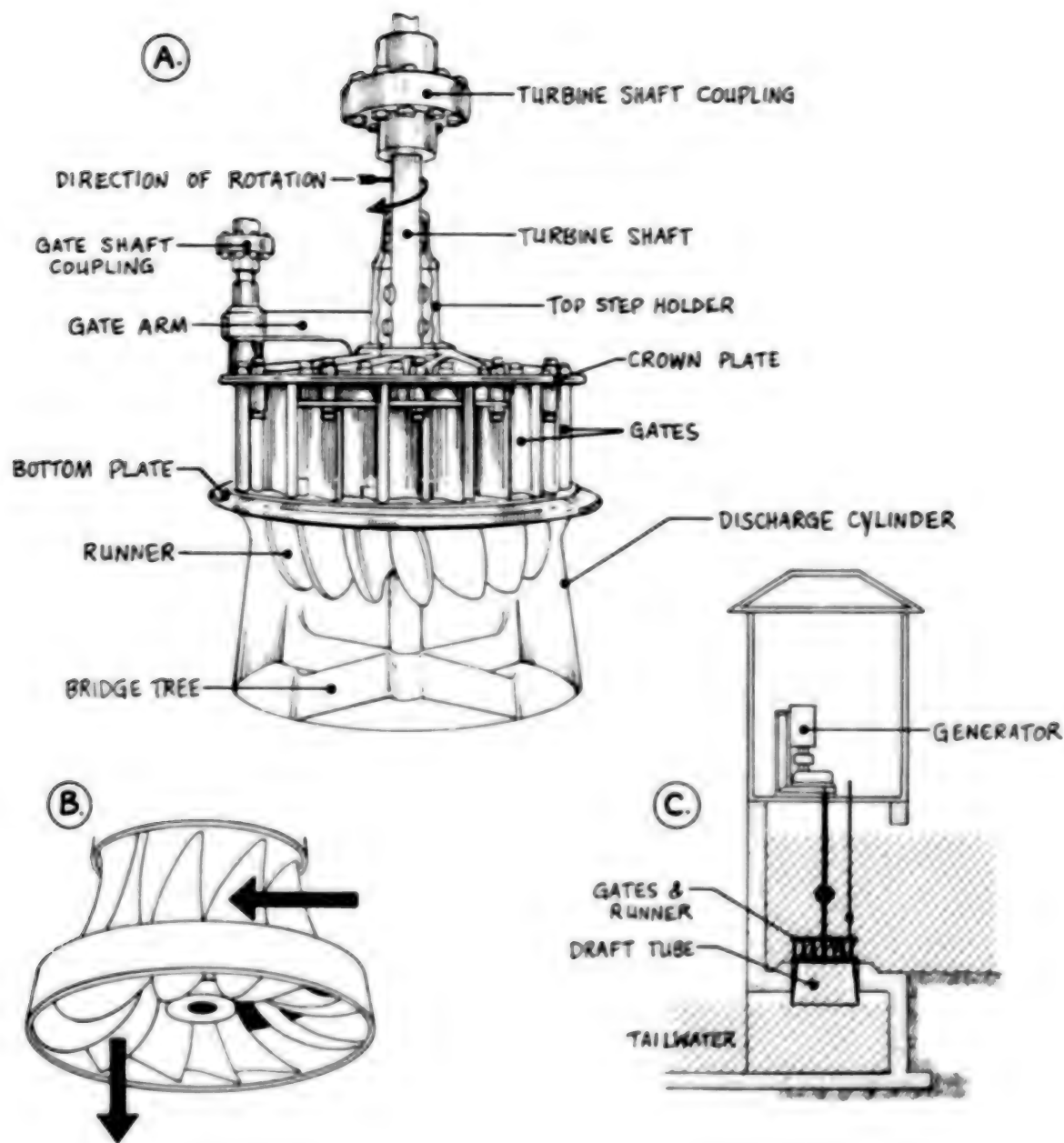


Figure 35. Reaction turbines, I (The James Leffel and Company; Gilbert, G. and Gordon Ltd.). Francis. A. Francis turbine of Samson type in vertical orientation; B. Francis runner with flow paths indicated; C. An open-draft tube setting, one of many possible configurations for a Francis turbine.

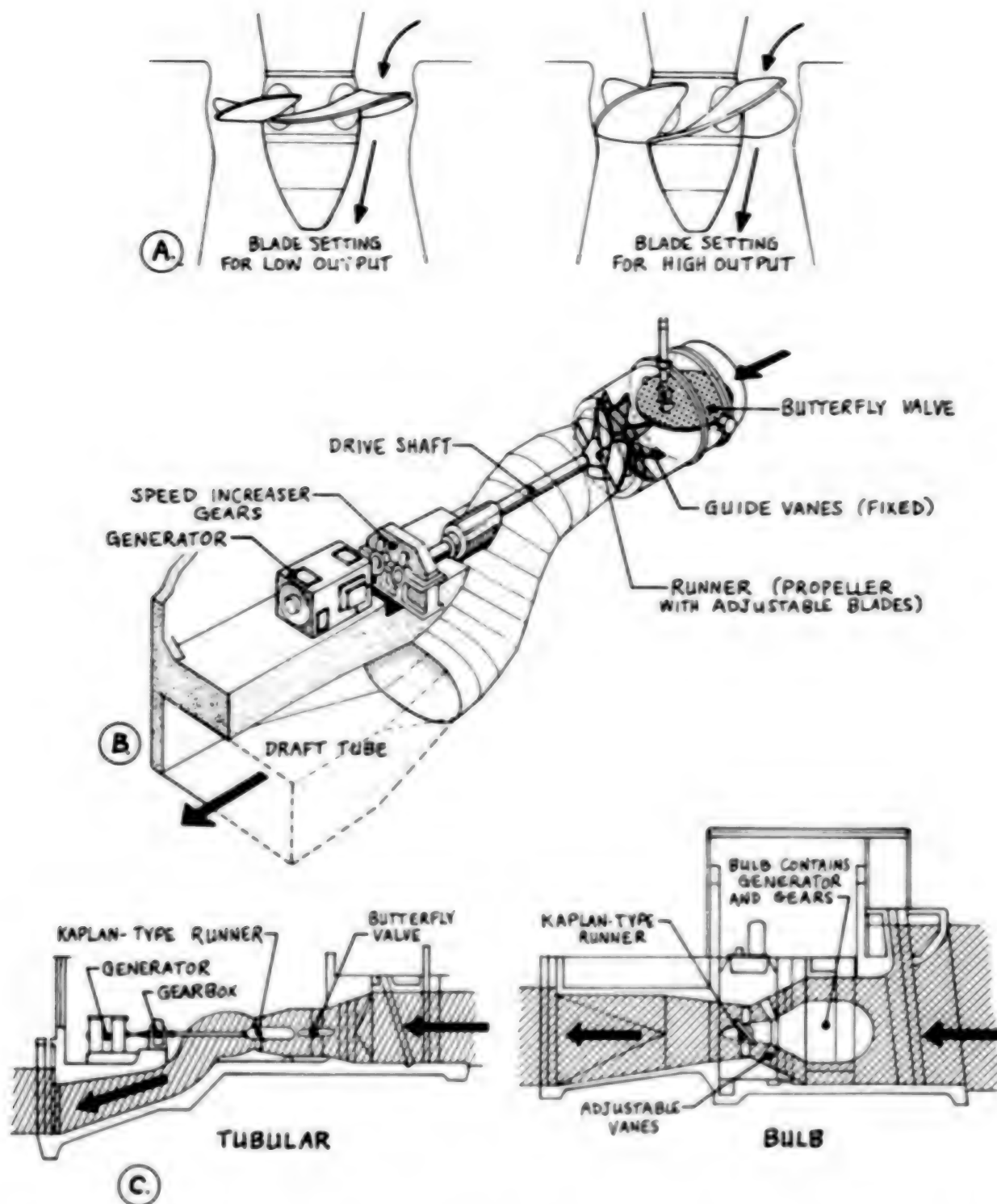


Figure 36. Reaction turbines, II (T. Lloyd Associates; Sörumsand A/S; Tampella Machinery and Engineering Group). Propeller types. A. Blade adjustments for a Kaplan runner; B. Tubular turbine and accessories; C. Views of typical tubular turbine and bulb turbine installations.

Bulb units (Fig. 36C) are also prefabricated and sold as a package of turbine plus generator. They use a tubular casing, but instead of having the generator somewhat removed from the turbine, it is mounted within the path of water flow. Thus, the generator and runner blades are completely submerged in water except for an entry passage for servicing the generator and runner bearings. The propeller is downstream from the bulb.

Rim or StraflowTM bulb turbines (Fig. 37A) also have no need for a connecting power shaft because the generator is built into the periphery of the runner blades and the wall of the tubular casing. The result is a smaller bulb than the usual type because it contains only the runner bearings and shaft. Rim generator turbines are an improvement on the usual bulb design because generator maintenance and cooling are cheaper when the generator is not confined inside a bulb.

The HydrolecTM turbine-generator comes as a double-cone unit (Fig. 37B). The outer cone is the casing while the inner cone holds the runner and the generator. With this unit, the propeller runner is positioned on the upstream end. This design is promoted as being especially appropriate for very small "micro-hydro" uses, such as at a single farm, home, or other facility with fairly small power needs. H-series units like the one in Figure 37B generate from 4 to 120 kW at heads of 1 to 10 m and flows of 3 to 35 m³/sec.

6.1.2 Engineering and Economic Considerations and Trade-offs

Not all turbine types are suitable for all levels of head, discharge, and power output. Figure 38 shows the ranges of heads over which the more common turbines have been installed and used successfully. Hydropower engineers typically use such data to make their initial selection of a turbine type for a given site.

For a given head, the cost for most turbines increases with the power generated, because the turbine must be larger to generate more power. However, the cost usually does not rise as fast as the increased power generated, so it is less expensive to install one large turbine than two smaller ones that would generate the same amount of power. Propeller turbines without blade adjustments are less expensive to install than Kaplans, but this benefit may be lost if flows fluctuate widely.

The analysis of cost/benefit factors in turbine selection is very complicated and site-specific. In general, however, tubular, bulb, rim (all reaction turbines) and cross-flow (impulse) turbines seem to work best for small, low head sites. Kaplan and Francis turbines are generally most successful in larger installations. Impulse turbines are best for high head sites (whether large scale or small scale in terms of power output) where high pressure can be obtained.

As discussed in Chapter 3, the goal of hydroelectric development is to obtain the highest annual power output for each dollar spent at a given

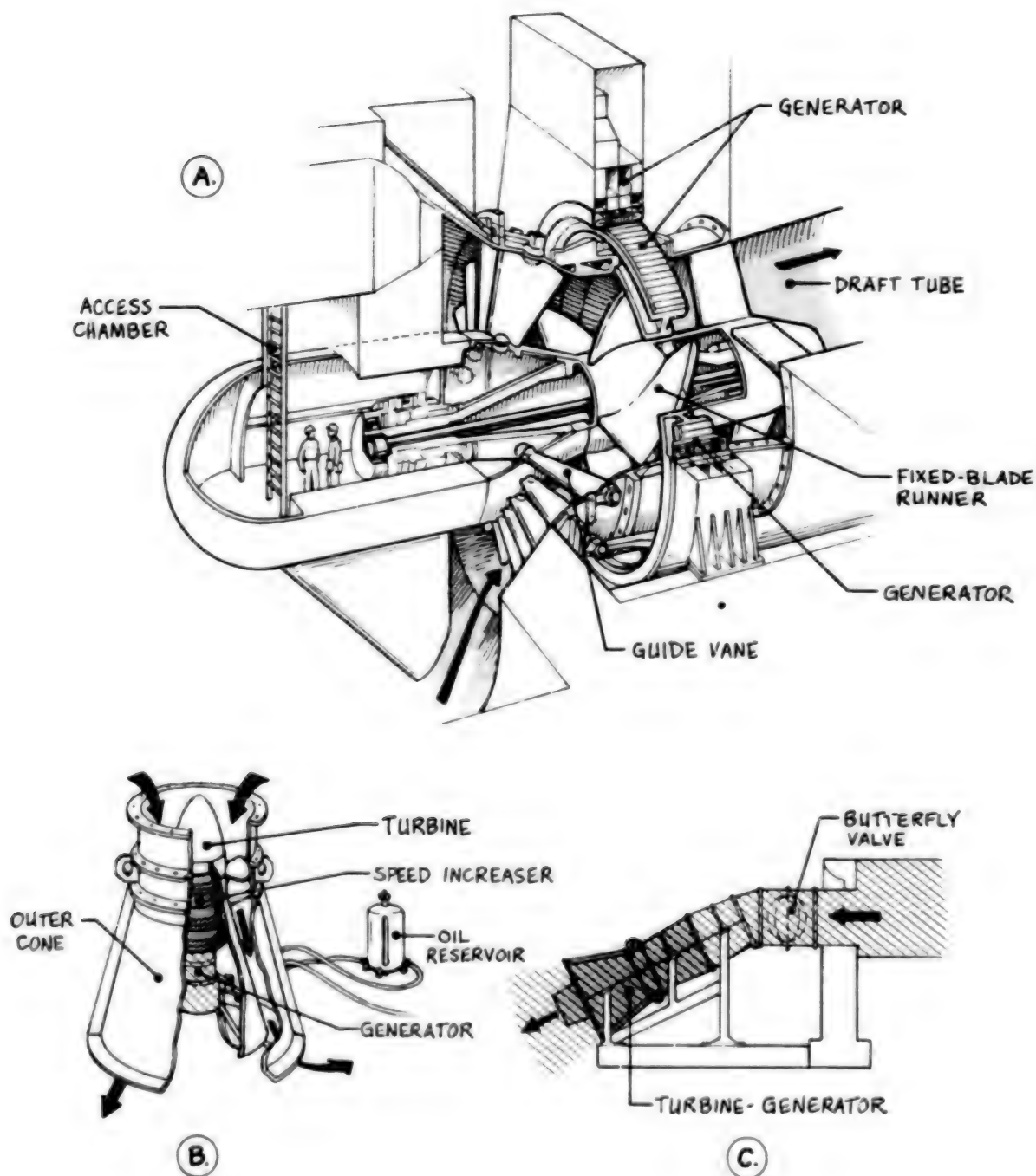


Figure 37. Reaction turbines, III (Straflo™ Group; Leroy-Somer, Inc.), Newer designs. A. Rim generator turbine of Straflo™ type; B. Hydroelec™ low-head turbine generator set, H-series design; with C. an inclined installation configuration.

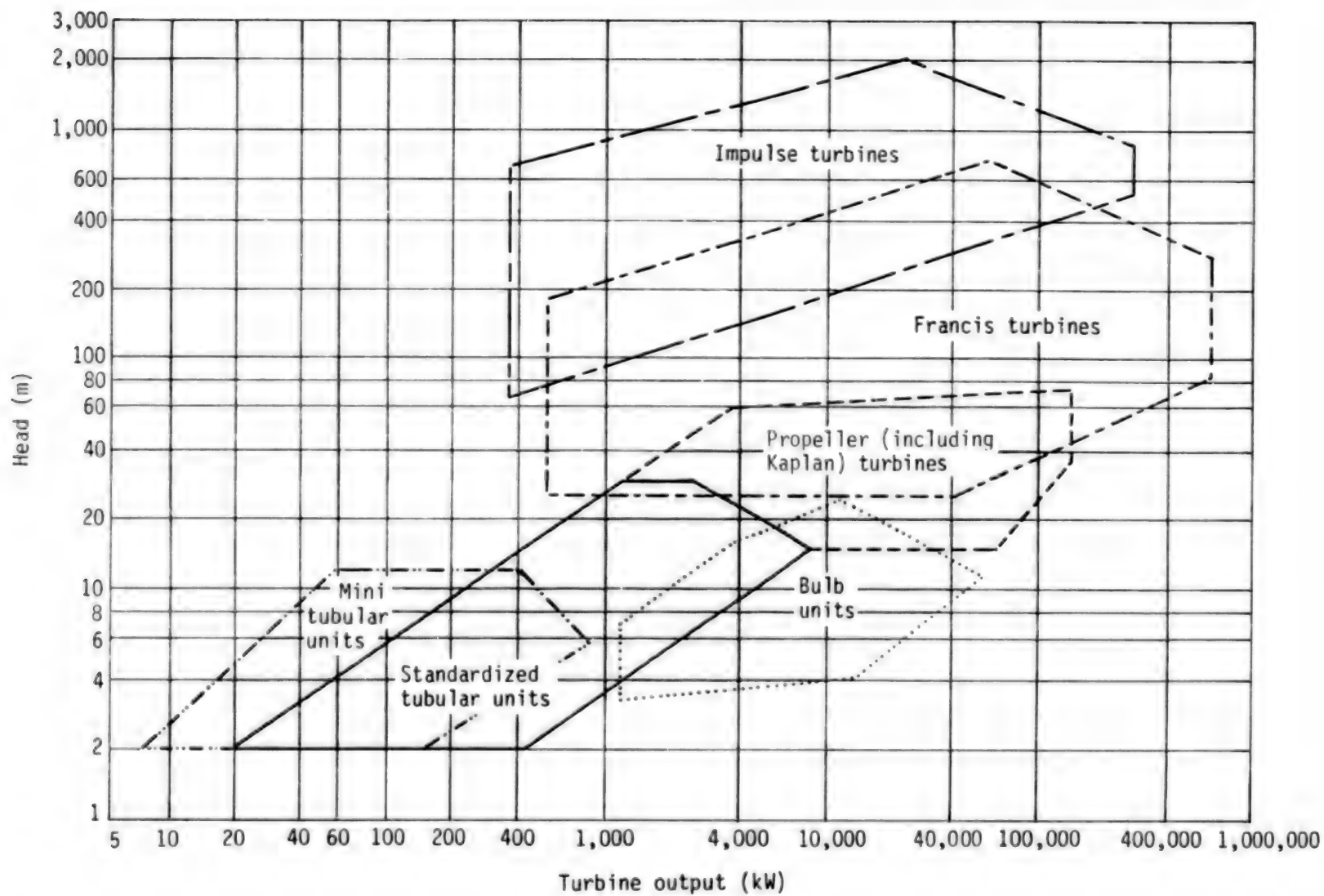


Figure 38. Common application ranges for conventional hydraulic turbines (Allis-Chalmers Hydro-turbine Division). Turbines operating in shaded areas use propeller runners.

site that is consistent with engineering, economic, and environmental constraints. Often, no single turbine is capable of efficiently capturing all of the available energy over the full range of head and flow that may occur. When this is true, the engineer seeks a combination of turbines (type or size), so as to be able to use as much as possible of the available head and flow. A typical case is shown in Figure 39. The diagram shows that, for flows which occur about 35 to 75% of the time, unit A alone would operate, and there would be varying amounts of spillage to meet instream flow needs (spillage is represented by the shaded area in the figure). For higher stream discharges, which occur with a lower frequency (about 25 to 35% of the time), only unit B would operate. At even higher discharges (greater than 100 m³/sec), both units would operate together and could use up to 130 m³/sec. All flow in excess of 130 m³/sec would be spilled. Of course, at many sites head and flow conditions are such that more than two units are warranted. Furthermore, if storage is available, little or no spillage need occur unless mandated for a nonhydroelectric need.

a. Environmental Effects, Trade-offs, and Mitigation. Turbines cause a number of environmental effects, by far the most important of which is the killing of fish moving downstream. Turbine mortality includes both acute mortality, which occurs during turbine passage, and delayed mortality, which is the ultimate result of injuries sustained during turbine passage. Delayed mortality includes death related to stress, excess predation, and progressive physiological deterioration.

Although a large number of turbine related fish mortality studies have been conducted with various types of turbines and various conditions of fish species, fish size, and life stage, the lack of data and serious methodological problems make generalization and the extension of conclusions risky (Bell 1981; Turbak et al. 1981). Also, few studies have been done with fish over about 20 cm total length, because originally most concern was for smaller downstream-migrating salmonid smolts. (It should be remembered that intake screens often prevent large fish from entering turbines.) In addition, few studies have addressed newer turbine designs (see Section 7.2, Unconventional Turbines) and turbines of very small size, which are used in many SSH projects.

There is no question, however, that hydro turbines of all types can kill fish. Mortalities ranging from 0 to 100% have been observed, depending on test conditions and turbine type (Table 9).

There are four recognized causes of fish mortality in hydro turbines (Bell pers. comm. 1982; Ruggles et al. 1981):

- (1) Strikes or mechanical damage due to being struck by, squeezed between, or cut by runner blades, wicket gates, guide vanes, or other obstacles.
- (2) Gas embolism due to passing through areas of subatmospheric pressure within the turbine.

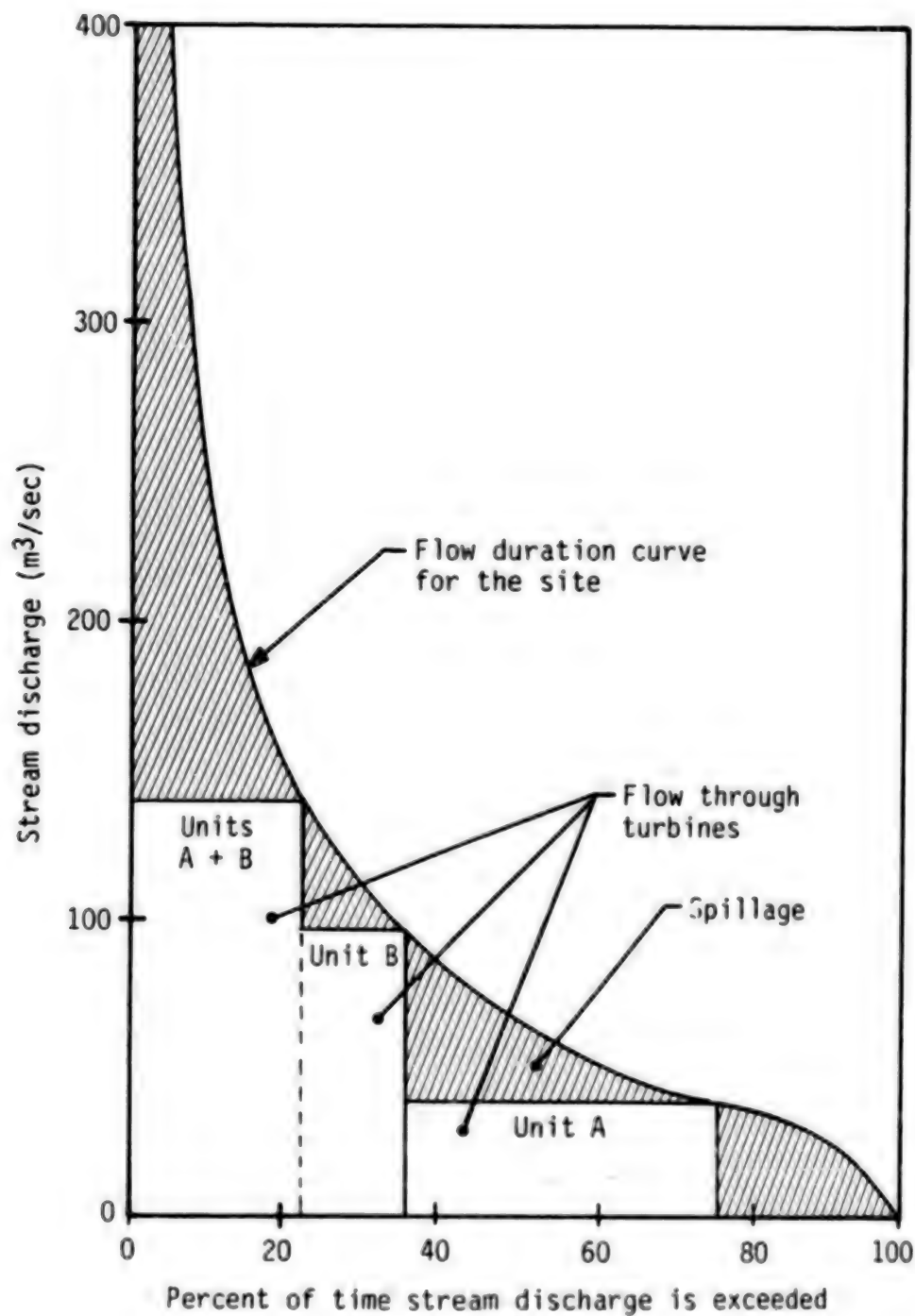


Figure 39. Utilization of discharge by turbines (T. Lloyd Associates). Note that diagram assumes turbines are located at the dam so as to meet instream flow requirements by regulatory agencies. The flow duration curve for a given site must be determined from stream gaging records.

Table 9. Examples of turbine-induced fish mortality results from various tests.

Turbine and test species	Head (m)	Fish length (cm) ^a	Mortality ^b (%)	Source
<u>Impulse turbines</u>				
Ossberger turbines				
Atlantic salmon	9.8	27.6	52.1-74.4	A
	9.8	16.4	22.7-44.4	A
Steelhead trout	9.8	14.0-16.6	13.3-53.8	A
Rainbow trout	9.8	8.5-13.3	6.3-38.4	A
	9.8	23.3	50.0-62.1	A
Striped bass	9.8	6.74-7.0	53.5	A
	9.8	8.3	54.5	A
	9.8	13.6	34.4	A
American shad	9.8	8.6-8.9	100	A
<u>Reaction turbines</u>				
Francis turbines				
Atlantic salmon	12.2	15.0	10.6 + 2.3	B
	118	13.5-18.5	42-72	C
	various	? "smolts"	30-50	D
Coho salmon	76.2	9.8	28.0	B
Chinook salmon	31.7	7.0	0	B
	59.2	7.0	33	B
Sockeye salmon	39.6	8.6	10.5	B
	43.3	8.6	9.2	B
	76.2	9.7	34.0	B
"Native" salmon	106.8	3.0-5.3	32.6	B
Steelhead trout	106.8	7.6-16.5	41.9	B
Rainbow trout	106.8	5.1-8.9	27.5	B
	106.8	3.8-5.8	28.8	B

Table 9. continued.

Turbine and test species	Head (m)	Fish length (cm) ^a	Mortality ^b (%)	Source
Kaplan turbines				
Atlantic salmon	15.5	21.0-36.0	4.9-13.11	E
	6.1	19.05	11.5 ^c	F
	various	? "smolts"	10-20	D
Chinook salmon	22-30	11.4	5.0	G
	26-34	11.4-12.7	11.2	G
Steelhead trout	26-34	15.2	9.6	G
American shad	15.5	45-60	? 50 ^d	E
Blueback herring (includes 5% shad)	15.5	7.0-9.8	45.5-99.9 ^e	E
Alewife	?	"yearling"	44-60	F
Bulb turbines				
Atlantic salmon	8.84	22.5-35.0	2.0	H
Coho salmon	12	12.1 ^f	0.0	I
	12	12.5	9.1	I
Steelhead trout	12	17.9	3.1	I

^aMeasured prior to fish entry into turbine or immediately after passage through turbine.

^bData usually included both acute (direct) and delayed (indirect) mortality and sometimes included a wide range of operating conditions for each turbine. Where ranges of results from many tests were given, the upper and lower 10% (extremes) of data were not included in the Table if there were at least 10 tests in the series.

^cInstantaneous mortality only.

^dAcute mortality only.

^eDeath of control fish due to stress made separation of turbine mortality difficult.

^fLength is for fish recovered at first recovery point, 61 km downstream.

Sources: A - Gloss et al. 1982

B - Semple 1979

Table 9. concluded.

- C - Ruggles et al. 1981
- D - Baltic Salmon Working Group cited by Ruggles et al. 1981
- E - Kynard et al. 1982
- F - Smith 1960 cited by Kynard et al. 1982
- G - Bell and Bruya 1981
- H - Knight and Kuzmeskus 1982
- I - Olson and Kaczynski 1980

- (3) Shock injury from cavitation; i.e., tissue damage resulting from exposure to extremely localized, very high, partial vacuum areas within the turbine.
- (4) Shear injury resulting from passage through water of extreme turbulence or layers of water that are moving at very different velocities.

The relationship between mortality and various characteristics of turbines and fish are summarized in Table 10. These studies suggest that susceptibility to injury and mortality varies by fish species during turbine passage. However, most studies have been done with juvenile salmonids, which seem to be better able to withstand turbine passage than shad, alewives, and herring. Only a few species have been used in turbine mortality tests in the United States (cf. Table 9).

Although no firm conclusions can be drawn from these data, some general relationships have been identified:

- Turbine efficiency has been related to turbine mortality in many studies of Francis and Kaplan runners (Bell et al. 1967; Olson and Kaczynski 1980; Bell and Bruya 1981). Generally, fish survival is best at highest overall operating efficiencies and, at least for small (less than 20 cm) salmonids, is numerically within a few percentage points of the efficiency value of the turbine.
- The internal design of the turbine clearly contributes to the mortality of large fish, because fish that are too big to fit through turbine guide vanes or wicket gates or between runner blades will definitely be killed. The smaller the fish, the more likely that passage through the turbines will be successful.

Therefore, turbines that have passages smaller than the fish in question or that operate at low efficiencies can be expected to inflict heavy damage. Ossberger (cross-flow) turbines are possibly the most threatening to fish because even comparatively large runners have quite small (30 to 40 mm) blade openings, which cannot be changed. Furthermore, their highest operating efficiencies, although covering a wide range of discharges, are usually below those of adjustable propeller (Kaplan) or Francis turbines. The openings of other turbines also become very small when wicket gates, guide vanes, or propeller blades are adjusted. The effective size of opening is also a function of the rotational speed of the runner blades; the faster the rotation, the smaller the effective opening. To some extent, speed of rotation is built into the design of the turbine (for example, the Turgo Impulse™ turbine is designed to rotate faster than the Pelton wheel); in other cases, it is a function of how the turbine is operated or maintained.

Table 10. Characteristics of fish and turbines known to affect fish mortality (T. Lloyd Associates 1983).

Turbine type	Fish characteristics		Turbine characteristics						
	Fish length	Fish species	Wicket gate opening	Head	Sigma	Tailwater elevator ^a	Operating efficiency	Runner speed	Power output
Cross-flow	+	+	NA	ND	ND	ND	NA ^b	ND	ND
Francis	+	ND	+	+	+	+	+	+	ND
Kaplan	+	ND	+	+	+	+	+	+	+
Bulb	P	ND	NA	ND	P	ND	+	P	P
Rim generator	P	ND	NA	NA	P	ND	P	P	P

^aCavitation or other pressure injuries usually involved.

^bThe operating efficiency of the Ossberger turbine changes little over its operating range, but its maximum efficiency is somewhat lower than the maximum for other turbine types.

+ = A factor in some studies

P = Probably a factor in light of results with other turbines with similar characteristics.

NA = Not a potential variable

ND = No data available or existing data insufficient to evaluate the role of this factor in fish mortality.

The type of turbine selected by a developer is dictated by head and flow considerations, as well as by the need for power. It is likely that, if a particular type of turbine is recommended for one place in a region, similar designs will be used commonly throughout the region because sites will share many characteristics.

b. Regional and seasonal considerations. Turbine mortality is a significant problem with far-reaching implications for anadromous fish (see Fig. 20). Turbine mortality depletes stocks on their journey to the sea and, thus, acts directly to limit population size. Frequently, a given population of downstream migrants is subjected to several turbines in series as it goes downstream (Fig. 40).

In Figure 40, it is assumed that all downstream migrants must pass through the turbines. This normally does not occur; spillage is typically high in spring, so that many fish go over the spillway instead. To the extent that fish avoid the turbines, mortality from that cause is reduced. However, spillways are also associated with fish mortality (see Section 5.2, Spillways). Multiple dams are a particular problem in New England and the Pacific Northwest (Columbia River Basin), where 10 to 12 dams occur in series in some watersheds.

The number, location, and sizes of turbines at each dam can affect the potential for turbine mortality in various ways. The amount and velocity of flow in relation to the discharge used by the turbines can be critical. As shown in Figure 39, a well-designed SSH plant will maximize the use of the available flow. When the flow is nearly equal to the maximum the turbines can handle, the probability of downstream migrants going through the turbines is high (unless mitigation measures are implemented). However, spillage, when it occurs, provides a way for fish to avoid the turbines. In general, the higher the proportion of flow spilled, the better the chance that the fish will avoid the turbines.

A second important factor in determining whether fish go over the spillway or through the turbines is the velocity of the spilled water compared to that entering turbine intakes. Studies on the Connecticut River have shown that smolts and juvenile clupeids tend to follow the rapidly moving spilled water rather than enter the intake canal leading to the turbines. If most of the water flow is over the dam during smolt migration, the fish in the pool will follow the fastest water and, therefore, pass over the dam in the spillage (O'Leary and Kynard 1980 cited by Kyard et al. 1982).

It is clear, then, that seasonal factors are important in determining levels of turbine mortality. Both the amount of flow in relation to turbine capacity and the times of migration (see Table 11), in relation to times of maximum discharge, are important determinants of mortality levels, no matter what the mortality-inducing characteristics of the turbines themselves are.

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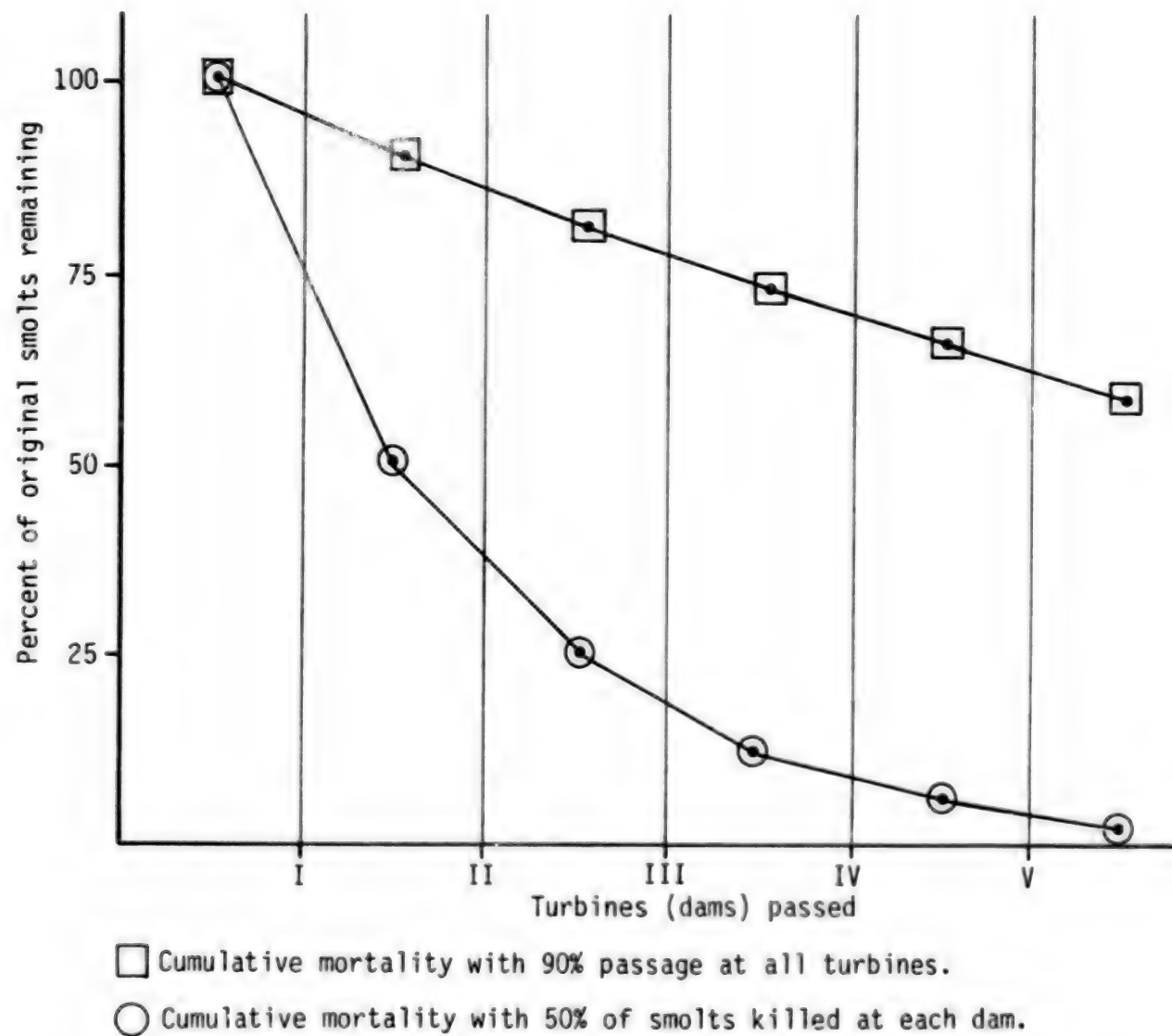


Figure 40. Survival of downstream migrants (assuming all fish pass through the turbines) (T. Lloyd Associates 1983).

Table 11. Life history information on anadromous fish species used in turbine-related mortality investigations (Turbak et al 1981).

Common name	Scientific name	Months/seasons in which the following activities occur				Downstream migrants	
		Spawning	Egg incubation	Rearing	Downstream migration	Composition	Size
Chinook salmon Fall	<u>Oncorhynchus tshawytscha</u>	Sept. to Jan.	Sept. to March	March to following April	April to June	Fry start emerging in March. Fry run peaks in April, but considerable numbers migrate in May, lesser numbers in June. May rear to smolt and migrate the following year.	Length of all chinook fingerlings: 51-57 mm
Spring		Late July to late Sept.	Sept. to March	March to following April (1 year or longer)	Spring and summer of following year		Length of spring chinook yearlings: 76-127 mm
Summer		Sept. to mid-Nov.	Nov. to following spring (1 year or longer)	March to March of following year (1 year or longer)	March to June of following year		
Coho salmon	<u>Oncorhynchus kisutch</u>	Sept. to March	Sept. to April	April to following spring (1 year or longer)	March to July of following year	May migrate to sea as fry, but most spend a year in freshwater and migrate as smolts. Main downstream movement occurs in May for both smolts and fry, but fry may be moved downstream throughout the summer.	Length of yearling smolts: 89-114 mm
Pink salmon	<u>Oncorhynchus gorbuscha</u>	Late Aug. to late Sept.	Late Aug. to mid-Oct.	Jan. to May	Dec. to May	Migrate immediately after emergence. Peak of run occurs in April.	Length of migrating fry: 25-38 mm
Chum salmon	<u>Oncorhynchus keta</u>	Mid-Sept. to early Jan.	Mid-Sept. to early March	Dec. to May	Dec. to May	Emergence and migration similar to pink salmon, except peak migration of fry is in May.	Length of migrating fry: 38-51 mm
Sockeye salmon	<u>Oncorhynchus nerka</u>	Aug. to Nov.	Temp. dependent, 80-140 days, fry emerge April to May	1-3 years	April to June	Do not migrate until at least yearling smolts.	Length of second-year 89-127 mm

Table 11. concluded.

Common name	Scientific name	Months/seasons in which the following activities occur				Downstream migrants	
		Spawning	Egg incubation	Rearing	Downstream migration	Composition	Size
Steelhead trout Summer, group A	<u>Salmon gairdnerii</u> <u>gairdnerii</u>	Feb. to March	Feb. to April	1-2 years	March to June	Do not migrate until at least yearling smolts.	Length of third- year smolts: 125-203 mm
Summer, group B		April to May	April to May	1-2 years	March to June		
Winter		Feb. to May	Feb. to July	1-3 years (avg. 2 years)	March to June		
Spring		Late Dec. to May	Late Dec. to May	1-2 years	Spring and summer of following year		
Atlantic salmon	<u>Salmo salar</u>	Late summer to early fall	Fall to spring	1-2 years	Spring to summer	Migrate as smolts.	Smolts are generally: 127-152 mm long

Note: Information on Pacific salmon and steelhead compiled from Department of Fisheries, Canada (1958) and Bell (1973); that on Atlantic salmon from Montreal Engineering Company, Inc. (1980).

Recently, it has been suggested that small turbines be added to spillways or outlets used to maintain instream flow. The idea is to make use of the energy in water that is spilled to prevent dewatering the reach from the toe of a dam to the tailwaters of the main turbines. Such an arrangement means that all the water leaving the reservoir for most of the year is going through a turbine. There is never any spillage around the turbines except during flood seasons.

c. Trade-offs. Conventional turbines operate at greatest efficiency when close to their maximum design loading. For most of them, the time of maximum operating efficiency seems to be the time of most successful fish passage through the turbine. When flows must be maintained downstream, and there is no spillage over the dam (low water season), steady flows may be maintained downstream by operating the turbine at less than peak efficiency. However, this procedure may cause increased fish mortality. The alternative, diverting water around the turbine, causes decreased power output. Another option is to install a small turbine in the low-level spillway so that it can be operated at full efficiency. Alternatively, the hydroplant could be operated in a peaking or pulsing mode (only possible if there is storage and a need for this type of power); this allows the turbines to operate at full efficiency, but streamflow below the dam fluctuates widely, which can result in several harmful impacts (see Chapter 7).

Multiple turbines are frequently employed at sites where the water supply is variable or at sites where the powerhouse is located well downstream of the dam and accommodating a minimum flow release would mean "wasting" water. Turbines of different size or even types may be used. Such a project enables the developer to maximize power production and yet meet instream flow requirements; however, it may mean that, for much of the year, nearly all flow passes through one or another of the turbines. Thus, the efficiency of bypass devices becomes important where downstream fish passage is a concern. Also, if the intake to the turbine located at the dam is deep, water quality below the dam could be a problem when there is no spillage.

d. Mitigation. Mitigative measures for turbine-induced fish mortality fall into six general categories: designing the project to avoid turbine passage by good intake design, location and operation; selecting the least damaging turbines; adjusting operational schedules to minimize mortality (avoid peaks of migration); providing downstream passage devices; adjusting size, number, and locations of turbines within the system to minimize damage; and replacing stocks lost to turbine mortality with hatchery-reared fish. Combinations of these approaches are possible (see the Mitigation Handbook for further discussion).

6.2 UNCONVENTIONAL TURBINES

6.2.1 Description

Recent interest in new sources of energy has encouraged the development of numerous new turbine designs and suggestions for creative uses of existing equipment. The field of SSH turbine engineering is expanding rapidly, with numerous turbines in various stages of design, testing, and field installation. Some of the turbines described below may never have wide application; others may become important because they offer ways to develop sites not suitable for ordinary hydroelectric turbines.

Some of the newer turbines and new applications of old equipment are described below and an attempt is made to evaluate some of the claims that the equipment will have less severe environmental effects than conventional equipment. However, it is important to keep in mind that there are very few, if any, field test data about the equipment described that provide needed engineering, economic, and environmental information.

a. Thrusters and pumps. Commercially available marine thrusters and propeller pumps, running in the reverse of the usual direction, have been suggested as substitutes for conventional turbines at SSH sites. Unlike many conventional turbines, pumps and thrusters lack a governor and do not have adjustable blades (Mayo 1982). They are designed to operate efficiently at one design pressure (head) and runner speed and, therefore, lack some flexibility. However, pumps are becoming increasingly more common because they have a number of economic advantages over scaled-down conventional turbines. Pumps are mass produced and, therefore, can be built more cheaply than individually designed conventional turbines. Often they can be completed at the factory and are ready to generate electricity after being lowered into a permanent station and connected to an induction motor. They can operate at relatively low heads and low discharges. Because of this feature, they have been installed at dams where instream flow maintenance was a constraint and at sites which were uneconomical to develop for other reasons. Pumps and thrusters are best suited for canals or in water supply and wastewater distribution networks, where flow is predictable and controllable. Some adjustment for maximum generating efficiency can be made at sites with a varying discharge by installing several small pumps (as turbines) and using as many necessary to accommodate the flow. In this way, those pumps that are operating are at their design speed and load and are used most effectively.

Figure 41A illustrates one design that may be appropriate for pumps used as turbines. It is a 300 kW unit installed by Kennebunk Light and Power Company in Maine. The unit was designed on the assumption that a discharge of $74 \text{ m}^3/\text{sec}$ would be available at any time the unit was to operate (Mayo 1982).

Proposed applications for pumps and thrusters in SSH projects are new uses, distinct from pumped storage hydroelectric projects, which are a separate, well-established technology not covered in this manual (see Turback et al. 1981 for information on pumped storage effects).

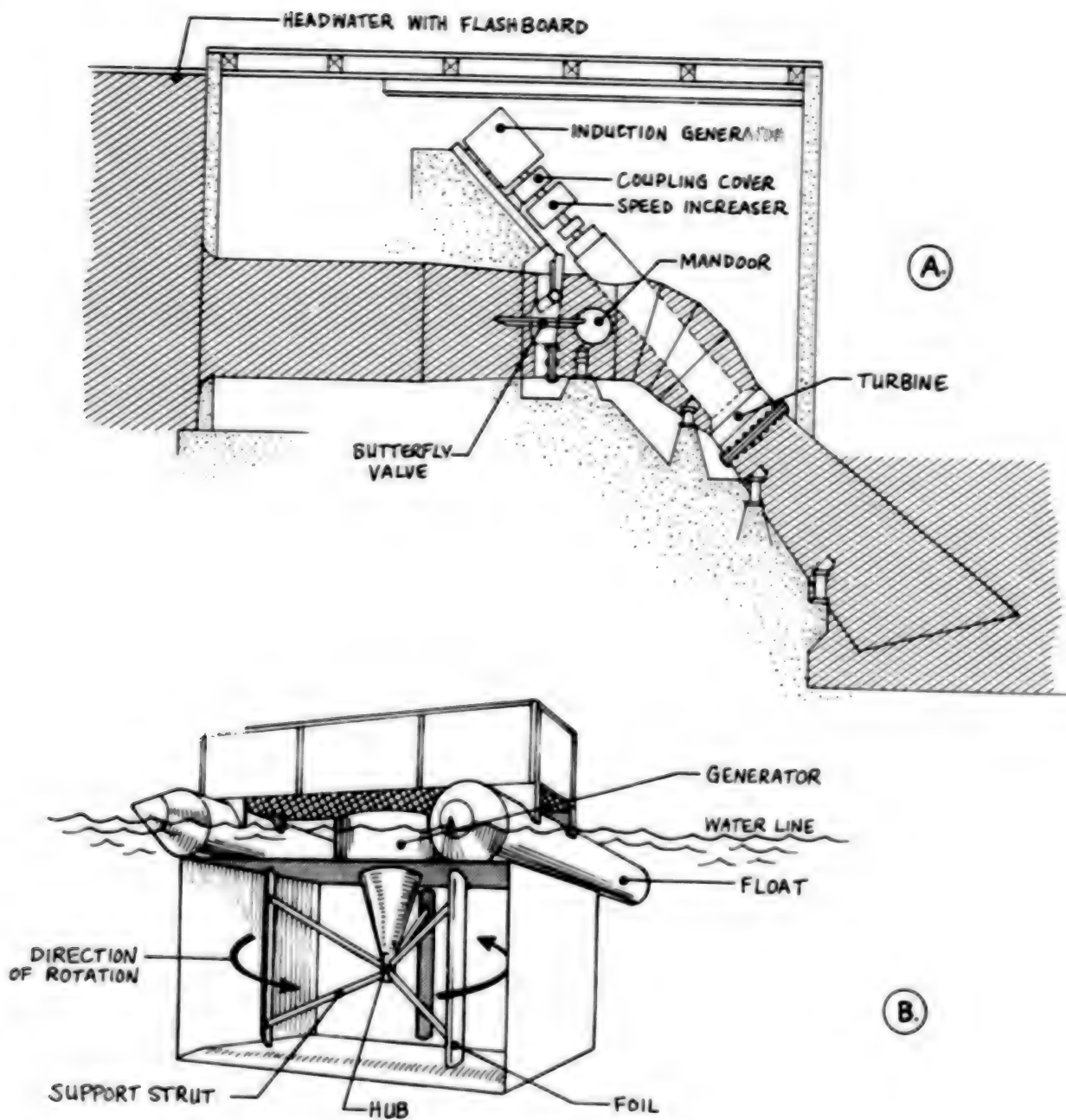


Figure 41. Unconventional turbines, I (Mayo 1982; T. Lloyd Associates). A. Pump turbine installation; B. Turbodyne in free-floating duct structure, which would be anchored to resist the current.

b. Hydrofoil designs. New turbines with designs based on hydrofoil principles are intended to operate directly in flowing water without any dam to raise head. The turbodyne (Fig. 41B) can operate with or without ducts and can be freestanding or placed in outlets in a low dam or dike. It uses vertically oriented, straight hydrofoils extended on struts from a central rotating shaft. The turbodyne is intended for use at very low head sites (0.5 to 2.0 m) and has been suggested for use in tidal environments.

The ducted turbine uses ducts to direct the flowing water toward a self-contained propeller turbine/generator. The ducts effectively increase the velocity of the flowing water, thus producing more power than if the propeller were merely directed against the flow. Both the ducted turbine and turbodyne are in the research and development stage.

The Schneider Lift-Translator engine consists of a series of hydrofoils on a chain that is formed into a circuit around two sprockets, much like a bicycle chain (Fig. 42A). A set of guide vanes directs the flow downward toward the first set of hydrofoils, where the water forces the hydrofoil to move downward around the circuit, causing the sprocket and shaft to spin. A second set of guide vanes directs the flow back upward into the hydrofoils on the return side of the chain circuit, adding more force to the movement of the chain, sprocket, and shaft. A third set of guide vanes restores the flow of water to its original path, thus minimizing head losses. The Schneider engine may be very advantageous at low head sites where the throat area (flow cross section) must be very large for significant water movement to occur, such as in irrigation canals, aqueducts, and drainage ditches.

c. Other designs. Other unique systems for possible SSH project use include scroll motors (Fig. 42B), the Norquest low head turbine, and the Gamell bladeless turbine. The scroll motor uses two spiral shells rather than blades. The Norquest low head turbine is reported to turn at low speed. The Gamell turbine has no blades, but directs the water through orifices in the runner surface as the runner spins. It is premature at this time to determine if these turbines will be suitable for commercial hydroelectric applications.

d. Regional considerations. The unconventional turbine concepts described here are intended for use in very low head sites (less than 15m) with comparatively constant discharge, such as irrigation canals, waterworks, and aqueducts. Most installations are likely to be in California, Arizona, and Florida, where extensive canal systems already exist. However, unconventional turbines probably can be used anywhere because there seems to be nothing more than possible icing problems or flow shortages to limit their application. The Schneider company, for example, estimated that 80% of the terrain and more than 80% of the flowing water in America is appropriate for the use of its equipment.

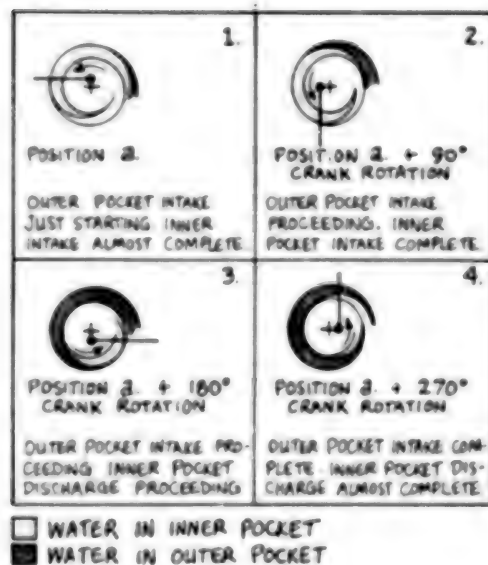
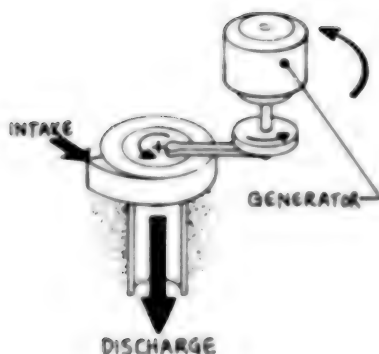
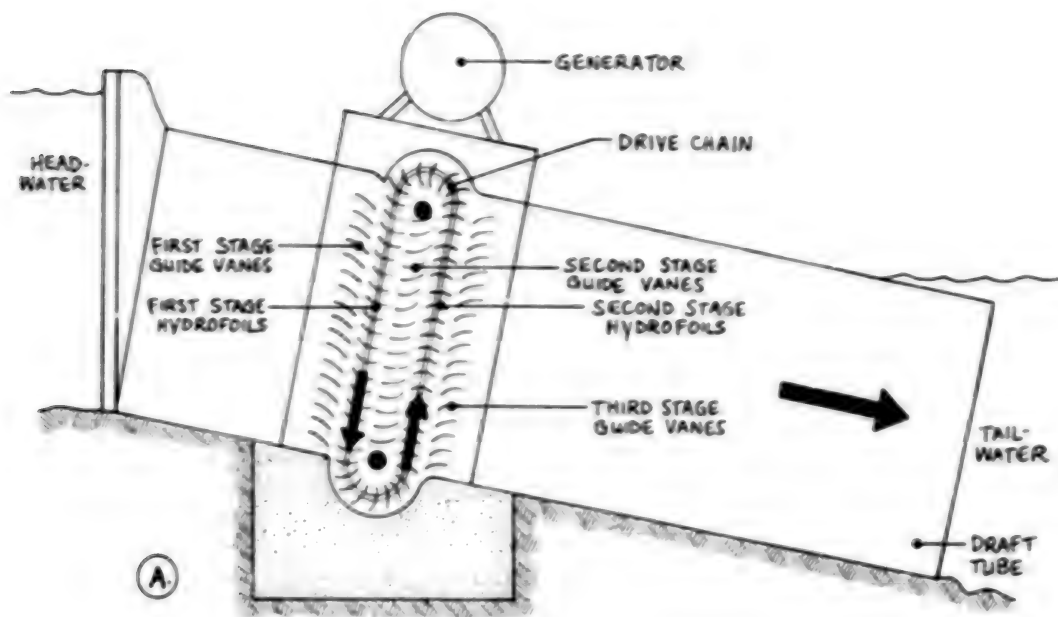


Figure 42. Unconventional turbines, II. (T. Lloyd Associates; Chappell and McLatchy 1981). A. Schneider lift translator engine in longitudinal section; B. The Scroll motor, with stages of water flow through it during one revolution.

6.2.2 Engineering and Economic Considerations and Trade-offs

The new turbine technologies are difficult to assess because few field data are available on whether or not the new turbine designs have fewer engineering or environmental problems than older designs. However, the new turbines are all capable of being mass produced and, therefore, could benefit from economies of scale if they ever come into wide use for new hydro sites. The success of a new turbine technology could be very rapid because it is aimed mainly toward very low head sites, which are numerous.

6.2.3 Environmental Effects, Trade-offs, and Mitigation

In conventional turbines, low efficiency and small openings within the turbine have been associated with high fish mortality rates (see Section 6.1, Conventional Turbines). For unconventional turbines that use fixed propellers (e.g., pumps), efficiency may be suboptimal during much of the operating time, and fish mortality may be high. This is because the propellers, pumps, and thrusters derive much of their economic benefit from the use of ready-made equipment, which cannot be adjusted for changes in flow. Also, most pump propellers are small compared to Kaplan runners and small openings between blades have been implicated as a cause for turbine mortality. The effect of the small openings may be magnified if, as has been suggested, several small propellers are used to provide a wide range of power output for various heads at a single site.

Where fish are plentiful, the combination of lower average operating efficiency and the smaller size of pumps may mean that fish mortality would be higher for the pumps and thrusters than for comparable yielding conventional plants. However, so far the overall effect on fish may have been small because most of the applications for thrusters and pumps have been in canals or waste collection and water supply lines, in which fish are lacking anyway.

Turbine designs using hydrofoil principles are intended to be used free-standing in a stream, floating on the underside of a barge, or placed in openings in a low head dam or tidal gate. Both the ducted turbine and the turbodyne may accelerate the flow in the immediate vicinity of the turbine blades, so there may be a tendency to draw fish into the blades at speeds somewhat greater than the prevailing current speed. On the other hand, it is quite likely that, when used in a free-standing mode, both turbines may provide a cover for fish and a substrate for fish food organisms, especially if floated on barges. Little is known about the types of support facilities that might be needed on shore for such an SSH facility. There may be requirements for antifouling, ice and debris removal, as well as servicing operations. Ducted turbines and the turbodyne should be considered experimental from an environmental, as well as an engineering, point of view at present.

The Schneider engine is presently being tested in two irrigation canal installations in California (75 and 170 kW). While the runner is unlikely

to cause cavitation and, hence, avoids this source of fish injury, a fish passing through the Schneider lift translator faces five sets of guide vanes or hydrofoil edges and three points at which a set of blades is moving in the direction opposite of the blades the fish has just passed between. The total travel length through the engine varies from 25 to 348 cm, depending on the model (power output). It seems likely that water shearing and mechanical chopping and grinding forces would be considerable for all but the smallest fish.

Because of the low speed of the Norquest turbine, there may be less hazard for fish than with most other turbines; however, no field work has been done to substantiate this. With the Gamell turbine, orifice size places an absolute limit on the size of fish that can pass through safely. In addition, shear effects from rapidly swirling water and pressure differences between the upstream and downstream sides of the turbine could be important. However, it is not known whether these devices will work successfully in commercial SSH applications or what their effects might be on fish moving downstream.

In addition to fish mortality, the presence of a turbine in a canal may alter the sediment flow. If a sediment problem is to be solved by periodic dredging or draglining of canals, turbidity will increase. Wetland vegetation along the canal or its adjacent waters may be disrupted, and possible off-site problems associated with silt disposal could result (see Section 7.4, Maintenance).

a. Trade-offs. For unconventional turbine designs, trade-off factors are difficult to evaluate because many of the designs have never been in regular commercial use. In addition, most of the sites for which these turbines are suitable have no history of exploitation for hydropower. Field experience and monitoring of effects will be needed before reliable statements can be made about the trade-offs associated with the unconventional turbines discussed here.

b. Mitigation. Mitigation techniques for reducing the mortality caused by unconventional turbines are similar to the techniques for conventional turbines; i.e., using screens and diversion structures to keep fish out of the turbines or replacing fish killed by the turbines with hatchery-reared fish.

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7. OPERATION AND MAINTENANCE-RELATED IMPACTS

The development of almost any SSH project offers choices, particularly in the early planning stages. Many of the options can significantly affect the overall impact of the project. Once the site is selected, decisions must be made on the height of the dam, the method and type of materials used to construct it, the choice of waterways and turbines, the method of site preparation, the design of facilities and the mode of operation for releases of water needed for power generation. From the standpoint of economic reward, the most desirable option for operating the project may not be the run-of-river mode and this can conflict with water uses for purposes other than power generation. The pattern of water flow from an SSH project has a great bearing on its environmental impact. From some projects, there is a fairly steady flow of water throughout the year, or at least seasonally. However, from other projects that are operated in a peaking mode, flows may fluctuate significantly over the course of a day or week.

Water flow patterns often depend on the primary purpose of the impoundment. In the case of retrofit projects, such as adding hydroelectric facilities onto a canal drop system, the original use dictates the flow pattern; therefore, flow may not change much after the SSH project is added. If the project is strictly hydroelectric, release schedules are based on the characteristics of the site, the needs for power in the marketing area, and the requirements downstream for other water uses.

The sections that follow discuss the environmental impacts of three different operational modes:

- Run-of-river, where the amount of water entering an impoundment is equal to the amount discharged over relatively short periods.
- Peaking, where water is stored, sometimes only for a short period, before being used to generate electricity to meet peak demands. Peaking requires impoundment and can produce very rapid changes in water flows downstream. Release schedules are typically designed to accommodate daily or weekly power demand.
- Multiple use, where the pattern of water flow is determined by the uses to which the project is put. In this case, water

is usually stored and released (although it may be discharged continuously), but the timing and magnitude of releases are determined by the other purposes of the project (e.g., flood control) and not by the need for electric power. Additional impacts due to SSH additions in this mode are usually small.

Figure 43 indicates the effects on downstream water flow typically associated with each operational mode.

The last section in this Chapter discusses both short and long term maintenance activities in SSH projects and their environmental impacts. Some maintenance activities are more or less constant, whereas others are required only occasionally in a plant's history or may not be needed at all. Some maintenance is associated with unexpected problems, such as dam weaknesses due to poor design or damage caused by a flood.

7.1. RUN-OF-RIVER MODE

7.1.1 Description

When the amount of water discharged from an impoundment over a relatively short time span for any purpose is equal to the amount of surface water flowing into it during the same period, the impoundment is said to be operating in a run-of-river mode. Many run-of-river impoundment projects designed for recreation or water supply can be retrofitted for SSH. In addition, numerous run-of-river diversions have been constructed specifically for hydro. Locks and dams often can be retrofitted for run-of-river hydro, and other water drops, such as for irrigation, also operate in the run-of-river mode. The Cornell University Fall Creek Hydroelectric Plant is a typical small run-of-river plant.

Run-of-river hydro plants fall into two general categories: those with pondage and those without pondage. Pondage is water storage that enables the plant to achieve instantaneous fluctuations in output throughout the week (Creager and Justin 1950). Most hydro plants have at least some pondage; those that do not are most commonly associated with a dam designed to maintain a given water level, such as for navigation. Pondage greatly enhances the usefulness of a hydro plant and increases its flexibility. With pondage, many plants can provide electricity either for the base load or the peaking load.

Run-of-river hydro projects are usually operated as follows. All "available" water is diverted to the turbines ("unavailable" water would include the amount necessary to meet instream flow requirements and any preemptive uses, such as water supply or irrigation). When the stream flow entering the reservoir exceeds the rated discharge capacity of the turbine's intakes (and intakes for other purposes), the pool elevation increases and excess water goes over the spillway as spillage. Spillage continues until the water level falls below the spillway or the flow is again equal to the rated discharge capacity of the turbines plus the

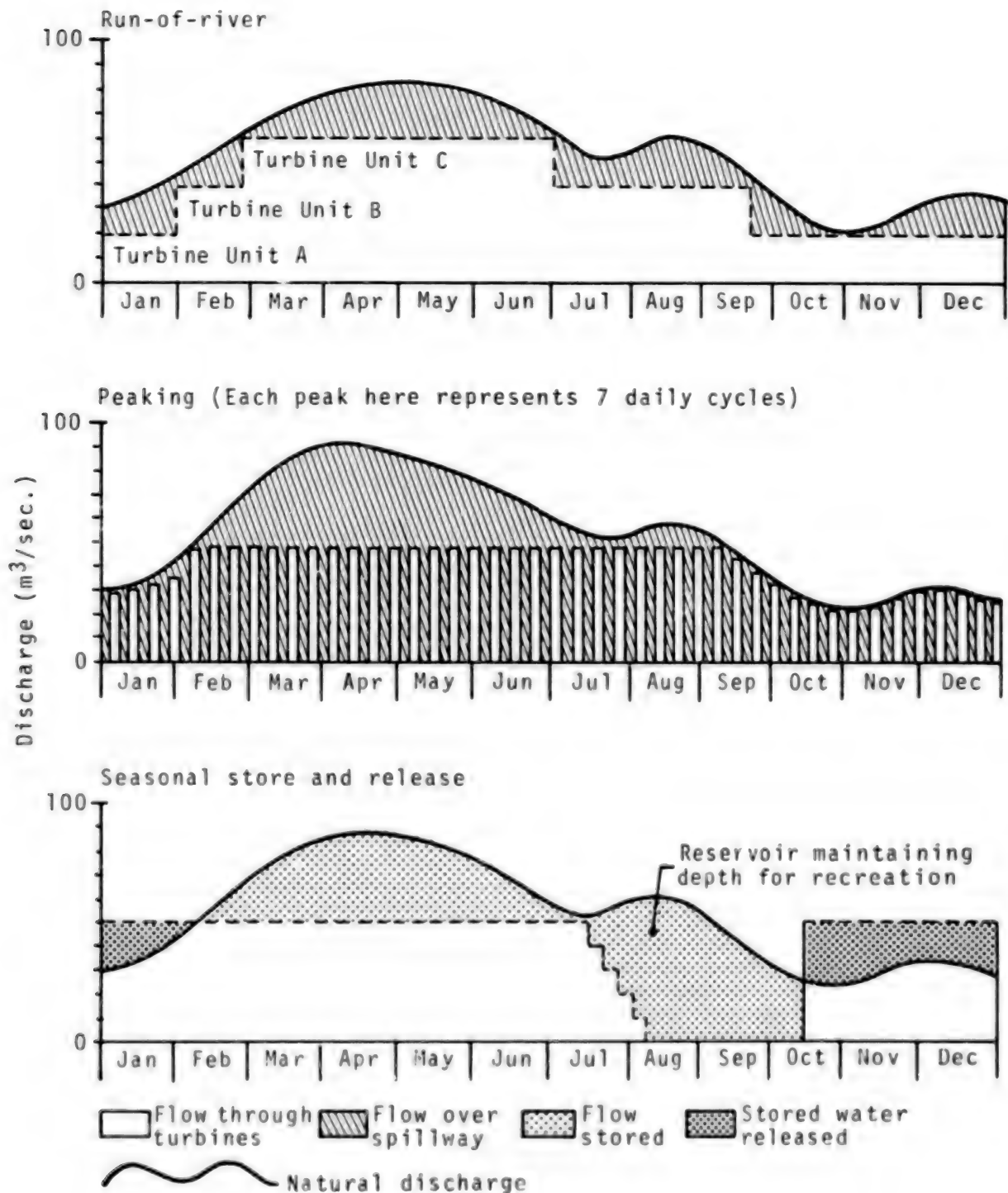


Figure 43. Hydrographs of discharge for three hypothetical, identical streams over an annual period (T. Lloyd Associates). The use of water for power production is indicated for three modes of operation: A. Run-of-river, B. Peaking, C. Seasonal store and release.

preempted amount. Electricity continues to be generated until there is insufficient water to operate the turbines and/or instream flow equals the minimum flow requirement. If instream flow falls still further, the reservoir (if there is one) may be drawn down to augment flow downstream.

7.1.2 Engineering and Economic Considerations and Trade-offs

Availability of water and significant variations in flow are the principal limitations for most run-of-river hydro plants. Instream flow requirements limit the output of many plants, especially for projects that are marginal economically because natural stream flow is low or the water is preempted for other purposes.

Run-of-river plants can be operated to provide either baseload or peaking power. Baseload run-of-river hydro plants must be able to run continuously. Therefore, the generating capacity of plants without pondage usually corresponds to the minimum river flow. Pondage (even in small quantities) is often a great advantage because it enables the plant to operate steadily even when daily fluctuations in flow occur.

Other ways of overcoming variations in flow include installing multiple turbines or a turbine with adjustable blades. Multiple turbines sometimes differ in size and type in order to utilize the full range of flows. New, more efficient turbines, capable of taking advantage of a wide range of flows, are also being developed. These turbines will enable many older plants to increase their capacity. In some instances, turbines with a rating similar to the minimum flow can be installed in the spillway of a dam, thereby extending the generating capability of the plant while maintaining flow. Another way to increase power production without changing the mode of operation is to increase the height of the dam.

The most economically advantageous plants are those capable of meeting both peak and baseload demand. However, power supplies often must be supplemented or the plant operated in a store-and-release mode in order to accommodate low flow periods.

The costs of installing new equipment or increasing pondage to increase generating capacity must be weighed against the cost of utilizing other sources of energy or operating for a longer period of time by shifting to a peaking mode.

Run-of-river projects without pondage are best suited to regions with an ample supply of water and are not well suited for arid regions or small watersheds.

7.1.3 Environmental Effects, Trade-offs, and Mitigation

a. Physical and chemical effects. SSH run-of-river projects without pondage seldom have large changes in discharge (in contrast to projects operated in a peaking or pulsing mode). However, long diversions are often associated with run-of-river projects and maintaining flow in the channel

between the toe of the dam and the confluence of the tailrace can be a problem. Run-of-river projects with pondage often can operate continuously and thereby supply baseload electricity. Plants which operate discontinuously under low flow conditions are not operating in a run-of-river mode. Such projects cause water levels to fluctuate and can result in impacts on fish and wildlife resources similar to those produced by peaking projects. These projects should be considered as peaking projects, even though it may be possible to discharge sufficient water from the impoundment to meet minimum flow requirements and/or equal the natural surface water discharge into the reservoir. (For peaking mode impacts, see Section 7.2).

Regulated flows, for hydroelectric power or any other purpose, alter natural stormwater hydrographs, thereby changing physical habitat conditions. Storage provided by an impoundment eliminates or reduces natural downstream scouring caused by periodic high flows. In the absence of periodic catastrophic floods, bed and bank stability are enhanced and there often is a reduction in channel capacity due to an increase in sedimentation rates and the absence of scouring.

The maintenance of instream flows adequate to protect aquatic habitats is the principal environmental issue associated with SSH facilities. In diverting water for hydropower, extensive areas downstream from the impoundments, between the toe of the dam and the confluence of the tailrace, may be dewatered or, at the very least, reduced in flow. In evaluating the extent and impact of dewatering, it is important to consider how the reduction in flow will affect water depth, current, temperature, nature of substrate, water quality, cover, subsurface flow and the use and value of the affected area to aquatic organisms. The physical alteration of riparian habitats also should be considered.

The run-of-river mode has comparatively little direct effect on water quality downstream from impoundments depending upon the size of the reservoir and depth of the outlet structure. Physical and chemical conditions within the impoundment are much more significant. The depth in the impoundment from which water is withdrawn and the volume of the withdrawals in relation to ground water seepage and flow from other sources largely determine water quality downstream. For other downstream water quality impacts, see Section 5.1 on impoundments.

b. Biological effects. Run-of-river SSH projects generally have less impact on fish and wildlife resources than peaking or pulsing plants. Impacts on plant and animal communities vary greatly and must be considered on a site specific basis. For new facilities, important considerations include the depth and quantity of releases for hydropower; anticipated physical, chemical, and biological conditions within the impoundment; and the anticipated operating plan for power generation. For retrofit projects, the same considerations are important, but only as they apply to hydro as opposed to other uses of the impoundment.

The run-of-river projects least likely to impact downstream fish and wildlife resources are those associated with low head dams and with the

powerhouse at the dam. The opposite extreme might be represented by a peaking plant with a long diversion.

c. Trade-offs. Any new dam alters flow regimes, often to the disadvantage of fish and wildlife resources. Hydro can provide opportunities, however, that benefit these resources. For example, increased flow reliability helps to stabilize water levels downstream and ensures the existence of an aquatic habitat that might otherwise be lost during dry periods as a result of natural seasonal variation in river flow. Also, increased discharge during low flow periods can benefit water quality, especially in rivers contaminated by municipal or industrial pollution.

d. Mitigation. Instream flow requirements can sometimes be met by installing turbines at the dam, rather than having diversions.

7.2 PEAKING MODE

7.2.1 Description

Peaking SSH projects are intended to provide electricity for peak demand periods, especially for a regional power grid. The power load of a utility (the demand for electricity) varies fairly predictably, as described in Chapter 2.

Most peak electricity currently is produced by oil and other fossil fuel plants that may be older and less efficient than the baseload plants. Topping systems, designed for the highest peak demands in the system, are usually gas combustion turbines that have low capital costs per kilowatt of capacity, but high fuel and operating costs. Typically, the cost of peaking power may be two to three times the cost of baseload generation.

Hydroelectric plants are able to produce electricity continuously (assuming flows are available), but they are also ideally suited technically to produce electricity to satisfy peak demands. Hydro can start quickly and respond rapidly to load changes by controlling the flow of water through the turbine. The high value of peaking power often makes hydroelectric short term store-and-release operations valuable. This is especially true where the utility is required to pay for purchased electricity on an "avoided cost" basis; i.e., the hydropower is priced on the basis of the costs that would have been incurred if some other means had been used to produce the power. This includes the fuel and other energy production costs and the savings associated with being able to retire old plants or avoid building new ones.

An SSH plant designed to operate in the peaking mode must have storage. Where seasonal flows are very low, storage must be provided by a reservoir that is large compared to the size of the hydroelectric plant. Peaking plants, therefore, frequently have large seasonal storage facilities and relatively high heads. They are likely to be found on small watersheds.

Figure 44 shows how daily load curves differ according to the type of economic development in the plant's service area. The peaking SSH plant supplies power along the upper parts of these curves, and, of course, discharges from the reservoir must follow this pattern. Figure 3 shows that there is also a weekly cycle in peaking plant operation due to the decreased electrical demand on Sundays. There are also seasonal variations in electrical demand.

Another function of a peaking plant is to act as a reserve in the event of failure of other plants or when demand exceeds expectations at some time other than the usual peak demand hours.

7.2.2 Engineering and Economic Considerations and Trade-offs

Peaking cycles and the size of individual releases are a function of energy demand, the availability of sufficient inflow water to restore levels in the impoundment after release, and the minimum flow requirements. Almost all projects are required to maintain at least some flow downstream, and the size of individual releases may be governed by other uses (such as water supply) of the impoundment.

Peaking projects are attractive from an economic standpoint because they represent an instantaneous source of electricity. In many parts of the country, especially in New England and the Pacific Northwest, fossil fuel and nuclear plants provide the base load, and hydroplants are brought on line as needed. In remote areas, hydro is more likely to provide baseload power, with a diesel generator providing peak or emergency power. Peaking is especially attractive from an economic standpoint when the buy-back rates public utilities pay are variable and reflect the incremental cost that a utility would have to pay to supply additional electricity. The buy-back rate of electricity in some States, however, is uniform, providing less economic incentive for peaking.

Sudden changes in flow affect the physical environment downstream from impoundments. Some releases are large enough to increase channel flow from a few cubic meters per second to several hundred within a few minutes. In some instances, the increase in flow begins with a virtual wall of water that sweeps downstream with dramatic effects on wetted surface area, water depth, and current velocity. High flows may be maintained from a few minutes to hours, depending on reservoir capacity, energy needs, and management objectives. When the release is completed, flow diminishes, sometimes nearly as fast as the initial surge, but, more often, reservoir releases are stepped down to minimize stranding of fish and other adverse impacts. Natural streams also exhibit wide variation in stream flow, but the extremes of discharge usually occur relatively gradually.

7.2.3 Environmental Effects, Trade-offs, and Mitigation

a. Physical and chemical effect. Large volume releases can scour the channel bottom and cause bank erosion. This can lead to increased turbidity and sedimentation downstream. Erosion can continue until an

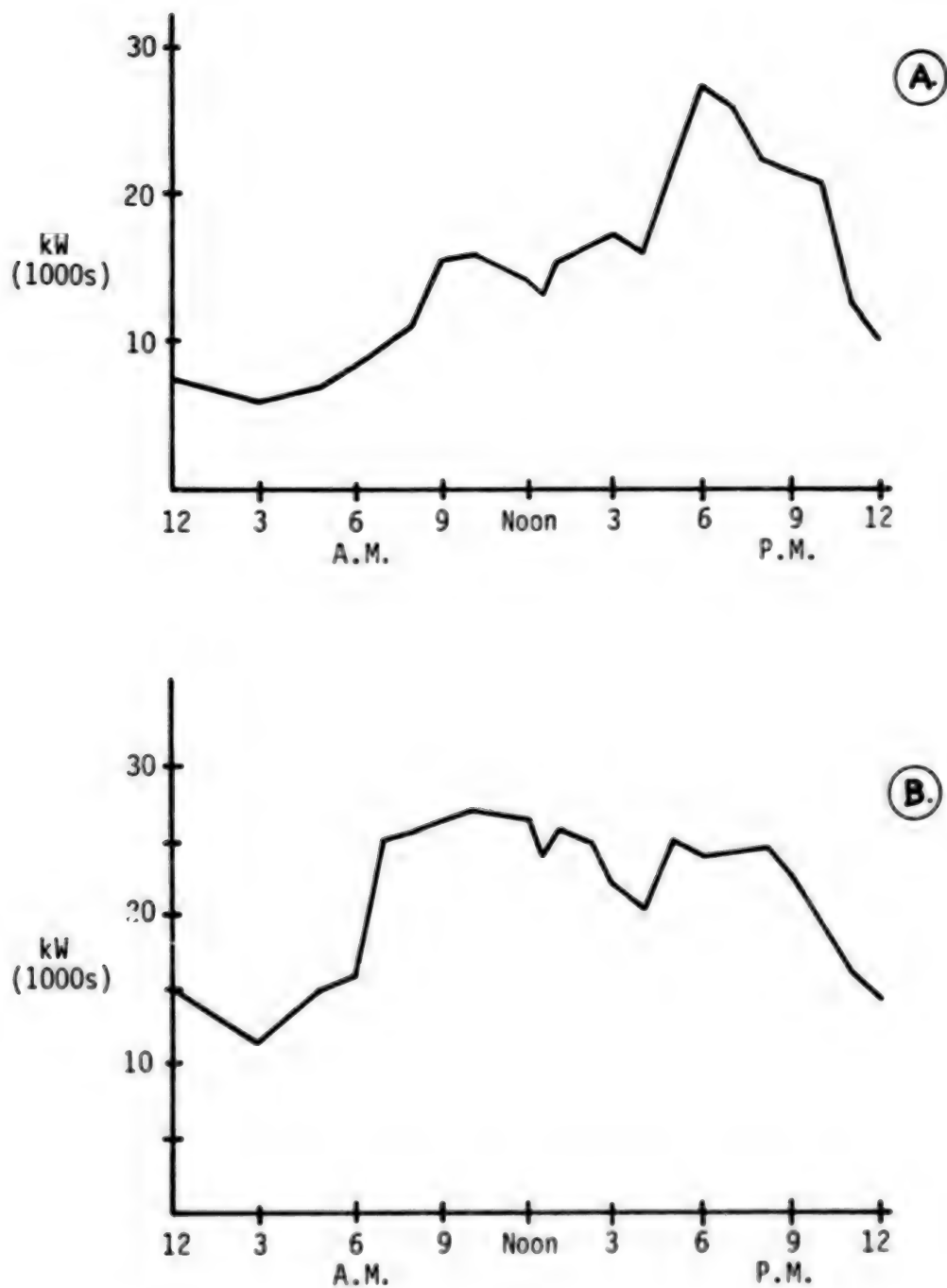


Figure 44. December peak-day load curves (Creager and Justing 1950). A. Power station dominated by domestic and lighting use of energy; B. Power station dominated by industrial users.

equilibrium is reached between particle size comprising the substrate and the capacity of the stream to transport material (Komura and Simmons 1967 cited by Walburg et al. n.d.). "Armoring" is a phenomenon resulting from scouring; stream beds become armored when currents sweep away silt, sand, and organic detritus, leaving only bed rock or cobble-sized rocks, a substrate unsuitable for spawning salmonids and for burrowing organisms important as fish food organisms.

Strong currents associated with large volume releases sweep away both inorganic particles comprising the bed and bank and organic matter, including leaf litter (an important food source in many streams), filamentous algae, invertebrates, and even fish.

Water levels may vary widely downstream from a hydroelectric station; flow may be limited to the main channel while the margins and side channels are dry during the storing mode (which may occur daily). When the plant is generating electricity, water depth may increase a meter or more, suddenly flooding previously dry areas. Besides the obvious problems of stranding and desiccation, aquatic organisms can be subjected to severe temperature fluctuations under these conditions. During the storing mode, downstream water temperature may approach atmospheric temperatures, especially if 2 or 3 days pass without a release. However, a sudden release of cold water can cause thermal shock that may have a greater effect than elevated water temperatures. Krenkel et al. (1979) attributed summer fish kills to the sudden release of cold hypolimnetic water low in dissolved oxygen from a hydroelectric project following several days of little or no flow.

Releases from impoundments can alter downstream water quality; the degree to which this occurs depends on conditions within the impoundment and the depth from which water is withdrawn. These factors are discussed in Section 5.1.

b. Biological effects. Periodic exposure of the channel margin may eliminate algae, aquatic macrophytes, and riparian vegetation (Kroger 1973). Loss of algae and macrophytes reduces the food supply for grazing insects and fish and eliminates cover for these animals; loss of riparian vegetation can result in increased bank erosion, loss of shade, increased water temperature and loss of habitat for aquatic and terrestrial animals.

Powell (1958) found that fast water releases from a power dam impoundment dislodged bottom dwelling fish food organisms, thus reducing the biomass of aquatic insects (per 0.1 m^2) by up to 32 times the amount found in the tributaries to the impoundment. Trotzky and Gregory (1974) concluded that slow currents downstream from a power dam reduced the diversity and abundance of swift-water aquatic insects, a possible explanation for the decline in the rainbow trout fishery in the Upper Kennebec River. Walburg et al. (n.d.) noted that mayflies and caddisflies, which are the most important fish food organisms in such cold water streams, are the groups most sensitive to fluctuating water levels. Midge and blackfly larvae, amphipods, isopods, and aquatic worms seem to be better adapted to survival in tailwaters. Very large populations of a relatively few species among

this group often can be found in tailwaters subject to fluctuating water levels. Many of these species avoid desiccation by taking refuge in moist areas, such as vegetation mats.

Increases in flow often result in a rapid rise in the number of aquatic insects in the invertebrate drift (Pearson and Franklin 1968 cited by Radford and Hartland-Rowe 1971) in a stream. Invertebrate drift occurs in almost all streams (Waters 1972) and typically exhibits pulses even in unregulated streams. The difference is that higher flows below hydro projects occur much more often than in unregulated streams, and this can deplete benthic communities (Powell 1958). Also, as Radford and Hartland-Rowe (1971) point out, the settling out of drifting invertebrates may be reduced because releases may eliminate suitable areas for the insects to settle in.

Rapid changes in flow pose many problems for fish. For example, eggs, larvae, and juvenile fish can be swept away. Fluctuating water levels may cause fish to become stranded or at least eliminate spawning habitat. Migration of salmonids can be delayed if water levels during peaking fall too low to permit movement. Sometimes natural barriers emerge at exceptionally low flows, preventing fish from moving except during the daily high flow period.

There is evidence that early developmental stages of some fish can survive brief periods of dewatering. Becker et al. (1982) reported that more than 50% of chinook salmon eggs buried in gravel survived 20 successive daily 12-hour dewaterings. However, less than 4% of the preemergent alevins survived 1-hour daily dewaterings.

Fluctuating water levels have many indirect adverse impacts on fish. For example, the loss of riparian vegetation and benthic algae results in a reduced food supply. A reduction in aquatic habitat areas may cause fish to crowd into the remaining available habitat, where they are more susceptible to predation, disease, and stress.

Although there is little information available associated with riparian habitats, it is likely that peaking projects would have adverse impacts on most animals, for example, young muskrat, beaver, and other animals that burrow into the banks could be drowned, and the nests of geese and ducks located in riparian habitat destroyed. Effects on amphibians and reptiles are likely to vary with the species and the season of the year.

Impacts from peaking operations exhibit spatial and temporal differences. For example, salmonids have more exacting habitat requirements and food preferences than many warmwater species; therefore, peaking projects located in coldwater fishery regions are more of a concern than those in warmwater regions. On the other hand, many warmwater streams support a coldwater fishery in tailwaters downstream from deepwater releases; intermittent releases into these tailwaters are not likely to be compatible with a coldwater fishery because of species requirements for a steady supply of cool, reasonably well oxygenated water.

c. Trade-offs. The potential damage to fish and wildlife habitat from fluctuating water levels associated with peaking is invariably greater than potential damage from run-of-river projects. However, store and release projects can provide electricity to satisfy a demand that might last for only a few hours. In some instances, the only alternative to a peaking plant is a new facility which, in the long run, might have greater effects than the peaking plant. Peaking plants often provide more flexibility than run-of-river plants in the choice of turbine type, size, number, and location.

d. Mitigation. Although it is impractical economically to adjust the operations of a peaking plant to allow upstream migration of fish, the impact of peaking operations can be substantially reduced by maintaining adequate instream flows for migration and by "stepping" releases up and down in order to minimize sudden changes in current velocity and water level. Stream channels can be deepened downstream from an impoundment in order to reduce the likelihood of stranding fish after a release.

The location of withdrawals is important. Problems may develop when warm waters receive large volumes of cold, deep water releases or vice versa. To avoid this, water can be withdrawn from different levels.

Most projects are required to maintain certain instream flows downstream from the impoundment in order to protect aquatic habitats. To meet these flow requirements may require a substantial drawdown in the impoundment. Thus, maintaining downstream aquatic habitats may result in an adverse condition in the impoundment.

7.3 SMALL-SCALE HYDRO WITH MULTIPLE USES

7.3.1 Description

An important consideration in SSH development is the exploitation of electric generating capacity at existing nonhydroelectric sites. These sites include canal drops, flood control reservoirs, irrigation storage reservoirs, and water-supply systems (see Chapter 3). The essential difference between SSH at multipurpose impoundments and single purpose hydroelectric projects is that, in multipurpose projects, SSH is secondary to, and governed by, the primary use of the impounded water.

The advantage of adding SSH to a preexisting water project is that some unused potential energy can be captured by installing SSH in existing flow conduits or building new ones. The SSH plant operates only when water is released for irrigation, municipal water supply, navigational flow maintenance, or some other use. The flow release pattern usually does not change noticeably after the SSH project is operational.

Many multiple-use sites involve some form of water storage. Storage reservoirs are generally on medium-sized tributaries rather than on the main stem of major rivers. These reservoirs frequently have little or no discharge downstream, but divert the entire flow into a pipe for water

supply use. Adding SSH projects to such dams has little operational impact on the stream because the preexisting use has already claimed all or much of the water. Of greater interest, from a fish and wildlife point of view, are those storage dams that discharge into a stream, such as flood control or navigational regulatory dams.

Figure 45 illustrates the different components of stored water that may be present in a large multiple-use dam. Note that the amount of water devoted to hydroelectric use is limited to only a fraction of the total storage amount.

Storage dams typically have a seasonal release pattern. For example, a dam designed to maintain the flow in a river used by barge traffic discharges whenever the river level is low (late summer and early fall in the Ohio Valley and Pacific Northwest, where many of rivers used for barge traffic are found). Flood control dams, on the other hand, are managed in anticipation of future floods, which occur during different months throughout the country. If an impoundment has both flood control and navigational uses, it follows a compromise pattern of releases. Regardless of the seasonal pattern of outflow, SSH project operation must be compatible with other water uses.

a. Regional considerations. There are two major ways in which operations at multiple use reservoirs are related to region. First, there is the natural pattern of runoff, which is controlled by rainfall and temperature. Depending on their purpose, multiple-use dams can, at least partially, compensate for variations in natural runoff patterns.

Second, the types of dams and their uses vary from region to region. In the Northeast, dams are often used for flood control, municipal water supply, and regulation of river levels for navigation or reregulation below a peaking plant. In the Southeast, flood control is particularly important. In the Ohio Valley, off-stream dams are used for flood control and to regulate the levels of the major rivers, which are used for barge traffic. In the Midwest and Southwest, irrigation is an important use, often with releases down the river itself, with farmers removing water from streams as they pass through their area. In the western mountains, flood control and water supply to distant major cities is an important use of reservoirs.

7.3.2 Engineering and Economic Considerations and Trade-offs

In multiple-use plants, SSH functions only when a flow is available. Therefore, the size of the SSH plant is based on the excess flow available for hydroelectric generation, not the total potential flow from the existing dam. Although it is often less expensive to install a SSH project at an existing dam than to rehabilitate an old hydro dam or build a new one, this advantage may be offset by insufficient excess flow to justify the expense.

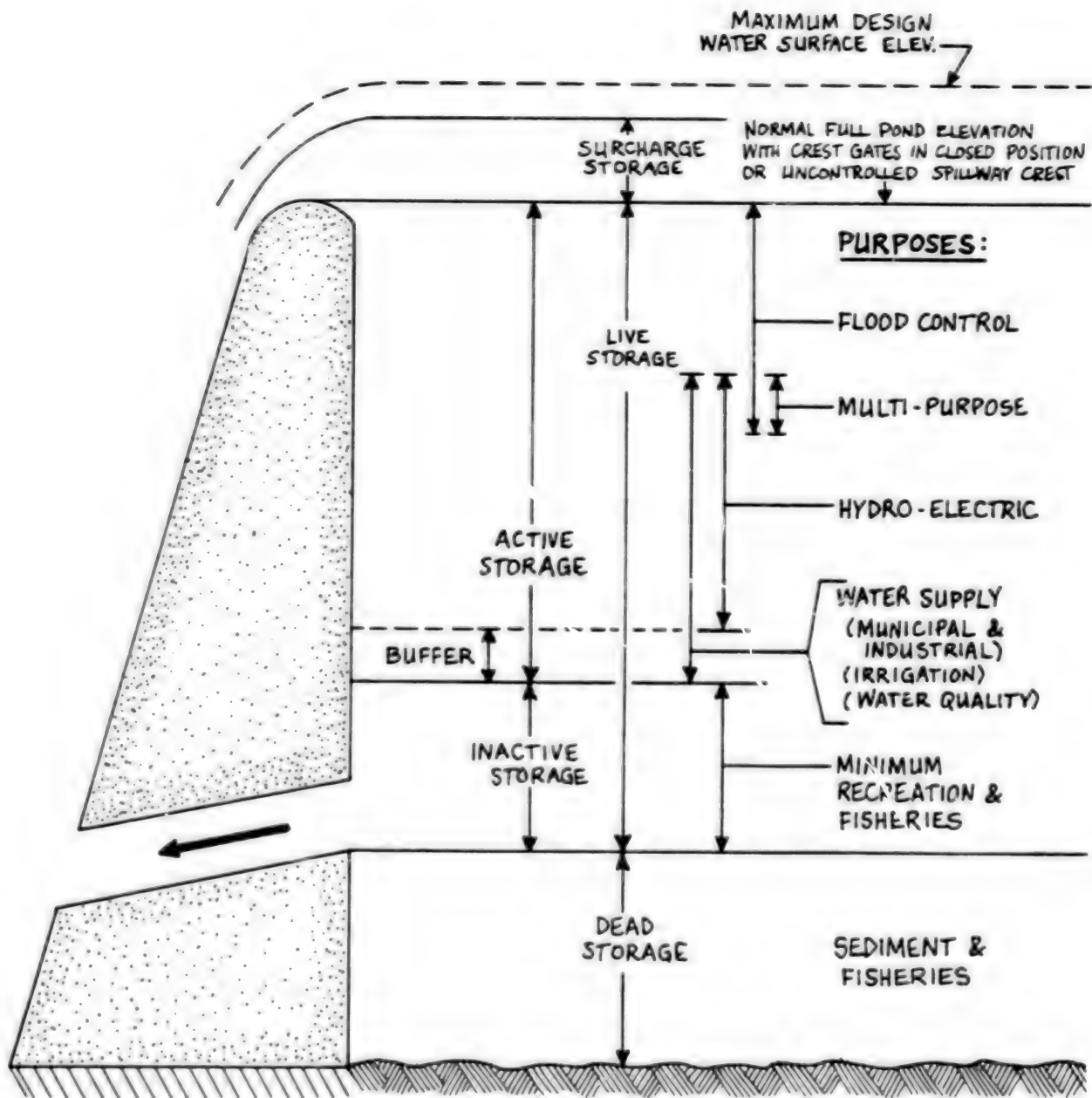


Figure 45. Different components of stored water in a multiple-use impoundment (U.S. Army Corps of Engineers 1979).

The principal benefit from seasonal operation of a SSH project at a multiple-use site is the generation of electricity with water that would be released anyway for other reasons. However, there are some negative factors. For example, the releases may occur during a season in which little additional electric power is needed, the initial cost to modify the reservoir for SSH may be too high to be recovered by power sales, or flows may be so unpredictable that the water supply for SSH is not reliable. An important consideration is the effect of SSH projects on the biological and physical structure of the reservoir, whether or not the water would be released anyway.

7.3.3 Environmental Effects, Trade-offs, and Mitigation

Some of the effects of a seasonal storage and release pattern are described below. However, there are preexisting effects that may change only imperceptibly as the result of hydro additions.

a. Physical and chemical effects. Seasonal storage and release results in a pattern of upstream (reservoir) water level changes and downstream flows that are often erratic and have little or no relation to natural flows in the area. If a dam is used for flow augmentation, flows in the stream below the dam will often be maintained, even when flows in similar streams in the area fall. If the dam is designed to maintain a certain pool level, other streams in the area may continue to flow while the stream below the dam may become dry.

Impounded water acquires different chemical characteristics due to stratification and sedimentation within the reservoir. Some of these changes were discussed in Section 5.1. Addition of a SSH project may have some positive effect on low dissolved oxygen and excess hydrogen sulfide content if air is allowed into the penstock or draft tube. How important this is to the stream environment depends on what fraction of the flow goes through the turbines and from what depth water withdrawals are made. Another way in which downstream water quality can be altered by the presence of a SSH project is when a new intake is constructed for the turbines. If water is withdrawn from a different level, downstream water quality is likely to differ from what it was prior to the modification.

b. Biological effects. The environment below many dams is well recognized for its adverse impacts on aquatic communities (Ward and Stanford 1979; Edwards 1978; and Section 5.1 of this manual). An example of the potential problems created for natural communities is provided by Kroger's (1973) study of the effects of water-level fluctuations below Jackson Lake, Wyoming, a reservoir used to hold water for potato irrigation, which governed the pattern of releases. Changes in downstream flow were characteristically abrupt; in one case, discharge decreased from 2.8 m/sec to 0.3 m/sec in less than 5 minutes. Figure 46 shows the annual flow pattern from the reservoir in 1965. Large numbers of invertebrates were killed when the flow dropped abruptly because they were unable to retreat fast enough from the drying zone.

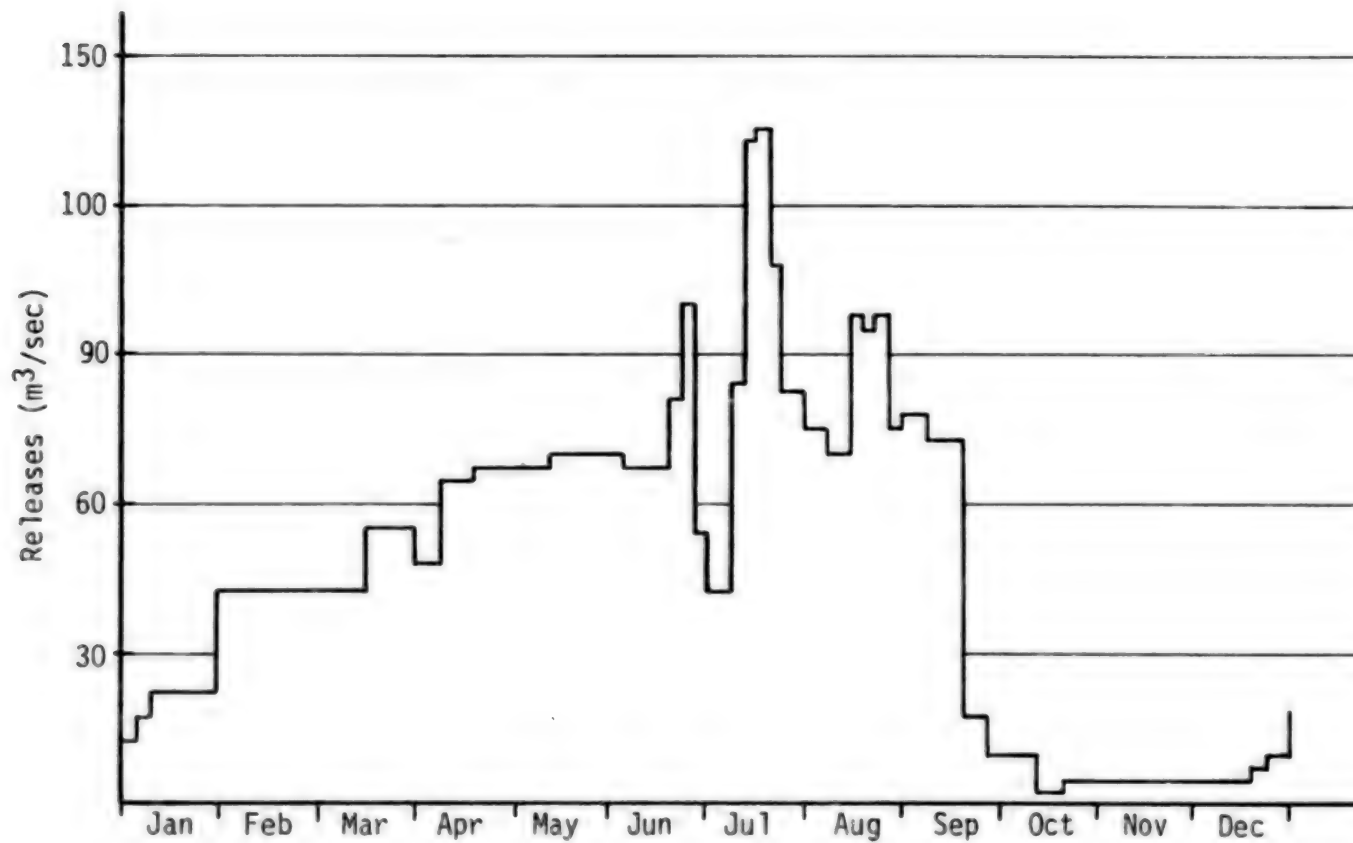


Figure 46. Release of water from Jackson Lake, Wyoming, during 1965 (Kroger 1973).

A study of extended reduction of flow in relation to trout populations was conducted by Kraft (1972). He found that diverting 90% of the flow from a trout stream for 3 months reduced the population of brook trout aged 1 year and older by 62%.

It is unlikely that the addition of a SSH project to a storage reservoir managed to provide seasonal releases will affect downstream fish and wildlife resources very much. However, if all the water is diverted through the turbines at certain times of the year, turbine mortality might have an additional impact. This impact is not unique to multiple-use impoundments retrofitted for hydro, however, and can occur whenever the flow is too low to allow for spillage.

Because SSH additions are so varied in design, it is impossible to predict the general effects of adding a SSH project to a storage reservoir managed to provide seasonal releases. The best approach is to work on a site-specific basis, asking the question, "What will be different at this plant after the SSH project is installed?" The impact is likely to be very little for a major reservoir with a small SSH addition.

c. Trade-offs. It is impossible to suggest trade-off factors for multiple-use projects with added SSH plants because the projects are so varied in scope and character. In general, little flexibility will be possible because of the water requirements of the original uses. If the need for electric power is great, or if the value of the original use of the reservoir has declined, it may be possible to change reservoir operations to be more compatible with hydroelectric production. It may be possible to take advantage of the addition of SSH to incorporate mitigation measures for both the SSH impacts and impacts resulting from the original uses.

d. Mitigation. The mitigation measures most likely to be needed at a multiple-use plant relate to the original use of the plant, not to the SSH addition.

7.4 MAINTENANCE

7.4.1 Description

To provide a predictable and dependable output of power, the dam and conduits, generating equipment, and electrical facilities of a SSH plant must be inspected and maintained. Few people are involved in this activity under normal conditions at modern small plants. The people involved may be responsible for several projects and go from one project to another according to a maintenance schedule. Ideally, maintenance is scheduled to minimize the loss of power output due to any shutdowns; i.e., during periods of low flow in most cases. Maintenance can be discussed in terms of its frequency.

a. Initial maintenance. During the first few months of operation of a SSH project, frequent shutdowns of all or part of the system may be

required to inspect turbines, tunnels, canals, stream banks and riprap, and gates and valves for signs of failure or excessive wear. Such shutdowns may occur unpredictably and, therefore, not necessarily at the most convenient time for either the developer or the stream environment. Once initial difficulties are rectified, the hydroelectric system should perform for many years with only the scheduled maintenance described below.

b. Routine maintenance. Intake structures, turbines, and electrical components are inspected routinely and cleaning, lubrication, and minor adjustments and repairs are performed as needed. Debris is removed from channels leading to the intake; trees and shrubs are cleared from the channel banks; and housekeeping is conducted in and around the powerhouse, parking lots, visitors' area, and roadways. Fish passage facilities are inspected for obstructions, damage, or failure to operate properly; monitoring seasonal use by migrating fish may be part of the maintenance procedure.

Typically, the turbines and generators are inspected in a shutdown condition about once a year. This activity is scheduled to coincide with low power output (water flow) whenever possible. Spillways, drainage systems, and roadways must be cleared of debris (such as trees and branches, leaves, and litter) on a regular basis. Large floating debris is typically directed over the spillway and into the downstream flow. Some debris may be burned or used in landfills.

According to the rate of tree and shrub growth, plants in transmission line rights-of-way need to be eliminated or cut back. Treatments include herbicide spray (broadcast foliar sprays of 2,4-D + 2,4,5-T and/or basal sprays with 2,4,5-T), mechanical removal with rotary mower or brush cutting equipment, or prescribed burning in appropriate areas (Arner 1977).

When routine inspections so indicate, overhauls of equipment or repair of civil works may be scheduled. Overhauls frequently require lowering the water in the affected area for an extended period of time. It is difficult to predict when or how often overhauls might be needed because many factors, including the quality of original equipment, climate, diligence in maintenance and minor repair, and operating conditions of each site, are involved.

c. Exceptional maintenance. From time to time, extensive corrective measures may be needed. For example, a dam may become unsafe for some reason, requiring an immediate, perhaps permanent, lowering of the water level. Floods may damage part of the system, requiring flashboards to be replaced or the rebuilding of spillways, intakes, or canals. Sediment may build up in the reservoir, resulting in significantly reduced capacity or disturbed flows toward intakes or within canals. Dredging or flushing of the system may be required, which may necessitate bringing heavy equipment to the site, finding spoil disposal areas, and adjusting reservoir levels.

Some parts of the system, including buildings, penstocks, bridges, fencing, transmission line towers, and road surfaces, may eventually

require total replacement. In such cases, "maintenance" may approximate a repetition of the construction steps needed to install these items initially (see Chapter 4, Construction-related Impacts).

d. Regional considerations. Maintenance of SSH plants varies somewhat according to region. The main consideration is climate, which determines such factors as:

- The need for flow alterations, blasting, and other actions to control ice in the stream.
- The need for road deicing chemicals.
- The growth rates of the plant species in transmission line corridors.
- The season of lowest flow when turbines are most likely to be shut down for inspection.
- The rate of sediment inflow to the reservoir, which determines the need for dredging or flushing.

7.4.2 Engineering and Economic Considerations and Trade-offs

Maintenance is normally performed according to a schedule. Activities and personnel usually are kept to the minimum required to protect the investment and ensure the satisfactory operation of the system. Because maintenance is a labor-intensive activity, it is subject to few technological cost reductions, except in the initial selection of low maintenance equipment. The trend in recent years, particularly with small hydro plants, has been to eliminate permanent staffing of the power plant and use periodic visits from custodial people or equipment specialists to meet maintenance needs.

It is generally more economical in the long run to perform maintenance of all types regularly and to repair defects discovered in equipment or civil works as soon as possible. Sometimes temporary budgetary problems are solved by deferral of maintenance. In the long run, however, this policy is unlikely to result in any saving of money.

7.4.3 Environmental Effects, Trade-offs, and Mitigation

a. Physical effects. Physical effects of maintenance are mainly hydrologic. When turbines are shut down at low flow, the headrace, turbine, and tailrace are dewatered so that they can be inspected. If there are no other turbines operating and there is insufficient water in the reservoir to go over the spillway, there is no flow below the dam at all. If turbines are shut down at high flow (not likely for routine maintenance but possible in an emergency), the excess flow goes over the spillway, with no net change in downstream flow.

Impoundment drawdowns are required to expose the upstream surface of the dam, multilevel intakes, and subsurface spillway inlets for inspection or repair. If water must be lowered rapidly for emergency maintenance, scouring and flooding downstream are possible. The banks and bottom of the reservoir that are exposed during drawdowns are particularly susceptible to erosion during storms because they consist typically of fine sediment with little or no stabilizing vegetation.

Another major hydrologic effect of maintenance has to do with sediment flows. All dams trap sediment to some degree, depending mainly on sediment input from upstream, but also on the flow path through the reservoir, particle size of the sediment, and design of the dam spillway, intakes, and other factors. If the sediment begins to interfere with operation, dredging and disposal of the spoil may be required (see Chapter 4). As sediment accumulates, particularly in the upper (inflow) end of a reservoir, wetlands of value to wildlife may be created. Depending on the needs of the project, these landforms may be destroyed or altered when sediment is removed.

b. Chemical effects. Maintenance may have direct chemical impacts, particularly from herbicides, insecticides, or oils used for dust control. Other chemicals likely to pollute the land or find their way into streams include vehicle fuels, lubricants, de-icing compounds, paint and possibly sewage treatment plant effluent. Nutrients and toxins in bottom sediments may be mobilized by dredging. Periodic flushing of sediment from impoundments can cause significant chemical and biological impacts downstream. A shallow impoundment on the Niobrara River in Nebraska was flushed 22 times during a five year period in order to maintain pondage and safeguard internal components of the generating facility (Hesse and Newcomb 1982). Fish kills and reduced abundance of macroinvertebrates downstream from the impoundment after flushing was attributed to the effects of lower concentrations of dissolved oxygen and an increase in turbidity, suspended solids and dissolved solids.

Air pollution is a possibility if organic debris from transmission line clearance, roadway clearing, and clearing of intake screens is burned.

c. Biological effects. Routine maintenance of SSH plants involves few direct biological effects. Travel to and from the site may result in road kills and there may be some disturbance of nesting and breeding, from visitors and hunting activities. However, site visits by maintenance personnel ensure that fish passage facilities, screens, nesting boxes, fencing, and other mitigation devices are operating as designed. Vandalism and fires, which represent serious potential hazards to both wildlife and people, are minimized by regular maintenance.

The indirect biological effects of maintenance may be considerable, depending on what is done and the design of the facilities. For example, cleaning intake screens may cause a temporary, minor turbidity problem in the tailrace; checking the turbine blades for cavitation results in a complete cutoff of water from the draft tube. If there is not enough water

to go over the spillway, or if other turbines or outlets are not kept operating, the downstream area can be dewatered, causing fish to be stranded and a loss of aquatic habitat.

Dredging, which should occur only infrequently, may introduce a large amount of suspended sediment into the water, which passes through the outlet works and proceeds downstream. Increased turbidity is harmful to fish. Sediment may settle on gravel beds downstream, eliminating spawning beds for stream fish and depleting the populations of many invertebrates suitable for fish food. Depending on what is done with dredge spoil, it may become a source of stream or lake pollution in the future.

Chemicals introduced into the environment, particularly pesticides used to control insects or other animals, may adversely affect wildlife. Herbicides will destroy vegetation used as habitat by territorial species and insecticides may contaminate the food chain.

Properly managed transmission line rights-of-way can provide enhanced feeding grounds for several wildlife species (Arner 1977). Although additional management may be necessary, transmission line right-of-way development and maintenance provides an opportunity for significant wildlife enhancement in an area.

A potentially severe, but unlikely, source of disruption of fish and other aquatic species is the occurrence of an emergency shutdown of equipment, a large reduction in the water level in the reservoir, or construction activity in response to safety problems with the dam. If the water level is lowered permanently or for prolonged periods because of dam weakness, fish passageway facilities may become inoperable, the water in the reservoir may become unacceptably warm or cold for certain species, and fish will be crowded into a smaller space with a loss of spawning sites along the shore. If the dam is damaged by a severe flood, repair of the dam, spillways, rip-rap along stream banks, and other structures is necessary. Potential impacts include dewatering, sediment influx, noise and vehicle hazards, and irregular operation of the facility. Such occurrences are very unlikely, and could, of course, happen at any dam, not just at SSH dams. Addition of a SSH project does not make catastrophes any more likely and may help prevent them because of the additional maintenance required by the hydroelectric plant.

d. Trade-offs. Environmental problems associated with maintenance are generally less severe than those involved in construction and operations. The gains in reduced disturbance to fish and wildlife that might result if maintenance were postponed or neglected are probably more than offset by the serious problems for the environment that can occur if the plant has to be shut down on an emergency basis or if mitigation measures cease working. In general, maintenance ensures predictability as far as plant operations and mitigation are concerned. Inadequate maintenance may result in unpredictable operation of the SSH plant, making it difficult to protect fish and wildlife.

e. Mitigation. Proper timing is the major method of mitigating maintenance impacts. Effective maintenance is the first step in ensuring that other mitigation measures (e.g., fish ladders and instream flow control) are working properly. If maintenance is effective, future problems that may require extensive construction usually are identified early enough so that plans for appropriate mitigation can be made. For example, if inspection reveals that a dam must be resurfaced, a trucking operation to move fish around the closed dam can be planned before the work is started.

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8. SMALL-SCALE HYDROELECTRIC PROJECT IMPACTS IN PERSPECTIVE

The preceding chapters of this manual described the multitude of environmental impacts associated with SSH technology in association with the related technological factors. This chapter outlines an approach to the comprehensive assessment of SSH project impacts, including a brief discussion of mitigation. The role of mitigation and approaches to mitigation planning are discussed in more detail in the Mitigation Handbook.

8.1 REVIEW OF THE POTENTIAL IMPACTS OF SMALL SCALE HYDROELECTRIC PROJECTS ON FISH AND WILDLIFE AND THEIR HABITATS

More than 100 separate environmental impacts attributable to small scale hydropower development were identified in Chapters 4-7 and are summarized in Table 12. This table illustrates the breadth of environmental impacts (i.e., air quality, water quality and quantity, aquatic and terrestrial habitat losses, etc.), categorizes impacts according to their source (construction, operations/maintenance, facility related), and indicates their relative importance to typical SSH developments.

8.2 THE CHALLENGE OF ENVIRONMENTAL IMPACT ASSESSMENT

Environmental impact assessment of SSH projects challenges the biologist for at least four reasons:

- Regional variations in fish and wildlife resources and differences between the design and operation of individual SSH projects preclude generalizations concerning their impacts.
- Small scale hydro is an evolving technology unfamiliar to many biologists. Impacts can come from not only the design and operation of SSH facilities, but also from construction and maintenance activities.
- Many impacts are not readily apparent, either because they are long term or they occur only as an indirect result of SSH.
- Some potential impacts can be avoided altogether by good planning, while most others can be mitigated, at least to some extent. Occasionally, SSH provides an opportunity for managers to enhance fish and wildlife resources.

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Table 12. Impacts of small-scale hydro projects on fish and wildlife and their habitats
(T. Lloyd Associates 1983).

Impact and Cause	Impact category	Importance
<u>Air quality</u>		
Air pollution due to open burning of construction waste	C	0
Air pollution due to open burning of maintenance refuse	OM	0
Air pollution due to forest and brush fires	C,OM	0
Dust from fill movements (vehicle and excavation)	C	X
Vehicle exhaust, air pollution from stoves	C,OM	X
<u>Water quality</u>		
Thermal increases downstream (surface outlet)	OM	XX
Thermal increases downstream (inadequate flow)	OM	XX

Table 12. continued.

Impact and Cause	Impact category	Importance
<u>Water quality</u> (continued)		
Thermal decreases downstream (deep release)	OM	XX
Lack of seasonal temperature pattern downstream (due to deep release)	OM	X
Abrupt temperature changes from peaking	OM	X
Low DO in reservoir	F,OM	X
Diurnal DO fluctuation in reservoir	F,OM	O
Low DO below dam	F,OM	XX
Air supersaturation (spillway)	F	X
Turbidity due to dredging and sediment resuspension	C,OM	X
Fine sediment dumped in streams (construction disposal)	C	XX
Excess sediment in stream (diversions and flushing)	C,OM	X
Excess sediment in stream (dredge spoil and construction waste)	C,OM	XX
Excess sediment in stream/lake (bank and bed erosion)	C,OM	X
Sediment from land into stream	C	XX
Decreased sediment load downstream	F,OM	XX
Nutrient increase in reservoir (sediment mobilization)	C	X

Table 12. continued.

Impact and Cause	Impact category	Importance
<u>Water quality (continued)</u>		
Nutrient increase in reservoir (land runoff)	C	X
Nutrient release downstream (reservoir releases)	C,OM	O
Sewage pollution (workers and visitors)	C,OM	X
Toxins mobilized from sediment (in low DO layer of reservoir)	F,OM	X
Miscellaneous chemical pollution (e.g. oils, fuels, and paint wastes)	C,OM	O
Road salt and sand in streams (maintenance)	OM	O
Herbicides in streams and lakes	OM	O
Pesticides in streams and lakes	OM	O
Aquatic weeds and algae (canal)	OM	O
<u>Water quantity</u>		
Flow cut off downstream due to reservoir filling	C	X
Inadequate flows downstream from SSH facility	OM	XX
Flow cutoffs for maintenance (canal and tailrace area)	OM	XX
Dewatering reservoir for maintenance	OM	X

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Table 12. continued.

Impact and Cause	Impact category	Importance
<u>Discharge fluctuations</u>		
Rapid downstream flow changes due to peaking	OM	xx
Fluctuating stream energy (from fluctuation flows)	OM	xx
Fluctuating reservoir/lake levels	OM	X
Water level fluctuating on reservoir shore due to peaking	OM	X
<u>Habitat quality</u>		
Stream habitat quality reduced (water shortage)	C,OM	XX
Stream habitat quality reduced (flow fluctuations)	OM	XX
Excessive scouring and substrate instability due to fluctuating flows	OM	X
Siltation downstream (loss of scouring flows)	OM	X
Turbidity injury to fish, invertebrates, and habitats	C,OM	X
Downstream eutrophication (reservoir releases)	OM	X
Aquatic plant species/aquatic habitat diversity decrease	OM	X
Eutrophication in reservoir (sediment mobilization)	C,OM	X
Eutrophication in reservoir (land runoff)	C,OM	X
Soil compaction (loss of infiltration capacity)	C	X
Soil erosion	C	XX

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Table 12. continued.

Impact and Cause	Impact category	Importance
<u>Habitat quality (continued)</u>		
Terrestrial plant species loss/terrestrial habitat diversity decrease	C,OM	X
Habitat altered by transmission right-of-way	C,OM	XX
<u>Habitat loss</u>		
Dewatered reach (when penstock used)	F,OM	XX
Floodplain wetland losses from inadequate and fluctuating flows	C,OM	X
Floodplain habitat cutoff by channelization and/or dewatering	C,OM	X
Filling and debris dumping in wetlands and shore areas	C	X
Inundation of terrestrial habitat above dam	C	XX
Lake shore/bottom wetland losses (inundation)	C	XX
Lake shore/wetland losses (drawdown)	OM	X
Inundation of fish spawning and rearing areas	C	XX
Inundation of flowing water habitat	C	XX
Loss of vegetable and soil cover at borrow pits	C	X
Loss of upland habitat for building and roads	C	X

Table 12. continued.

Impact and Cause	Impact category	Importance
<u>Organism losses</u>		
Vehicle noise	C,OM	X
Fish kill from blasting	C	O
Fishing increase	F,OM	X
Hunting increase	OM	O
Bird and wildlife disturbance by visitors	C,OM	O
Visitor (vandalism toward wildlife)	C,OM	O
Bird mortality at transmission lines	F	XX
Blocking of terrestrial animal movement (at canals or penstock)	C,F	X
Blocking of terrestrial animal movement (reservoir or buildings)	C,F	X
Trapping terrestrial mammals in canals	F	X
Borrow pit hazard to animals	C	O
Loss of aquatic mammal burrow sites	C,F,OM	X
Impoundment predators (fish) or fish	F,OM	X
Bird predators (of fish) in forebay and tailrace	F,OM	X
Stranding of fish and invertebrates downstream due to peaking operations	OM	XX
Disruption and washout of drift species	OM	X

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Table 12. continued.

Impact and Cause	Impact category	Importance
<u>Organism losses (continued)</u>		
Loss of fish food organisms	F,OM	O
Gas-bubble disease in fish	F,OM	X
Diurnal DO fluctuation resulting in fish kills	F,OM	X
Injury to fish-food organisms downstream due to low dissolved oxygen	F,OM	O
Thermal shock (warm or cold) due to peaking	OM	X
Fish upstream migration blockage (at dam)	F	XX
Fish delay in tailrace due to disorientation	F,OM	XX
Disease (injury) to fish due to congregation	F,OM	O
Increased current obstacle to fish movement (at diversion or during construction)	C,F,OM	X
Reservoir as low current barrier or delay factor in fish migration	F	XX
Reservoir thermal barrier to fish	F	O
Loss of reservoir species due to maintenance drawdown	OM	X
Spillway mechanical mortality (fish)	F	XX
Pressure effects on fish in penstock and other water passageways	F	X

Table 12. concluded.

Impact and Cause	Impact category	Importance
<u>Organism losses (continued)</u>		
Jet (shear) effects on fish in penstock and other water passageways	F	0
Thermal shock (cold to warm) to fish (from travel in deep release)	F,OM	X
Pressure shock (high to low) to fish (from travel in deep release)	F,OM	0
Turbine mortality (fish)	F,OM	XX
Fish injury by impingement	F,OM	XX
Interference with fish spawning (limited sites and inadequate water levels)	C,F,OM	XX
Spawning (fish, amphibians and reptiles) reductions due to reservoir drawdowns	OM	X
Reservoir biota depletion from entrainment	F,OM	X

Impact category (aspect of a SSH project most likely related to impact):

C = construction

F = facilities (e.g., dam or turbine)

OM = operations/maintenance

Importance (in general, at many SSH plants):

0 = slight importance

X = somewhat important

XX = very important

The challenge for the biologist/regulator is to select and correctly evaluate the pertinent environmental issues from the universe of potential impacts, identify feasible alternatives which could avoid or at least partially offset the negative consequences of a particular project, and, finally, specify a set of terms and conditions consistent with his or her agency's policies. Owing to the existing regulatory process, the successful developer is similarly challenged. He or she must perform a similar assessment, select alternatives which are feasible from an economic and engineering standpoint, and, at the same time, adequately address environmental and other concerns expressed by reviewing agencies.

8.3 FWS INVOLVEMENT IN FERC PERMITTING AND LICENSING PROCESSES

The Fish and Wildlife Coordination Act, the National Environmental Policy Act and Federal Energy Regulatory Commission regulations mandate the FWS to become involved in all applications for exemptions, licenses, applications for renewals, some license amendments, and draft and final environmental impact statements prepared by the Commission staff. Ideally, the Service should become involved in the planning and review process surrounding the construction of a hydroelectric power project as early in the planning stage as possible. The value of doing so cannot be emphasized too strongly.

The involvement of the FWS biologist in hydroelectric project planning includes the following:

- Provides ecological advice during formulation of plans for the construction of SSH projects and related activities in the Nation's waters and wetlands.
- Prepares comments and recommendations on applications for exceptions, licenses or preliminary permits to construct such hydroelectric power projects and related activities.
- Provides technical guidance and assistance to other government agencies and concerned citizens on environmental aspects of hydroelectric power projects and related activities.
- Provides technical guidance and assistance to local and State programs designed to further public education and awareness of environmental values and the actions that must be taken to reduce impacts on navigable waters and wetlands from water-resource developments such as hydroelectric power projects and related facilities.

8.4 SCOPING THE SMALL SCALE HYDRO PROJECT

Project scoping is an important first step in the impact assessment process. Many projects require relatively minor modifications to existing structural facilities and no change in the water release schedule, whereas

other projects, such as a new impoundment or major water diversion clearly have the potential to cause significant adverse impacts. Obviously, with limited time and resources, the biologist/regulator should concentrate on projects which are likely to have the greatest effect. Project scoping helps the biologist to allocate his or her time most efficiently.

To help scope the project, the biologist may want to consider the project in light of its apparent effects in the following impact areas:

1. Blockage of upstream and downstream movement of fish and fish food organisms, including both blockage of migration and direct and indirect mortality.
2. Inadequate or fluctuating downstream flows and upstream water levels.
3. Innundation resulting in loss or degradation of critical stream reaches, such as fish spawning/rearing areas and fish food production areas.
4. Loss or degradation of riparian floodplains and wetlands used for wildlife habitat and fish food production.
5. Degradation of water quality, such as reduced dissolved oxygen, sediment loading, thermal effects, and nutrient loading.
6. Loss or degradation of upland environments, including direct mortality to animals due to construction activities and transmission lines.
7. Concentration, entrapment, impingement, and/or entrainment by intake structures.
8. Turbine mortality.

The above listed impacts are generalized from the list of more than 100 presented in Table 12. Consideration of a limited list, such as this, can help the biologist to identify the major environmental issues associated with a particular project. In reviewing material supplied by the applicant, he or she may wish to make use of a check list such as in Table 13. Check lists help ensure that all of the information necessary to understand the project and to identify pertinent environmental issues has been provided. The check list can be helpful in organizing data and building an information file on each site. The headings indicate topics that need to be understood before project impacts can be predicted. It is likely, therefore, that because of regional variations in fish and wildlife resources, and the nature of SSH development, there is no universal check list, and each biologist should prepare their own based their particular needs and experience.

Table 13. Checklist for small-scale hydro impact assessment
(Knapp 1980).

-
- A. Project identification
 - B. Project description
 - 1. Dam
 - 2. Engineering specifications
 - 3. Operations design and multiple-use
 - 4. Relocation of man-made features
 - 5. Known competitive uses for water
 - 6. Interaction with other projects
 - 7. Socio-political interests and visibility
 - C. Site description and water quality
 - 8. Bank characteristics
 - 9. Water regime
 - 10. State water quality/stream classification
 - 11. Observed pollution problems
 - 12. Sediment history related to dredging
 - 13. Natural barriers
 - 14. Available water quality data
 - 15. Other designations/classifications
 - D. Fish and wildlife - general
 - 16. Rare, threatened, or endangered species
 - 17. Aesthetic and/or recreational values
 - 18. National Wetlands Inventory classification
 - 19. Applicable executive orders
 - 20. Other procedural requirements
 - 21. Public access
 - E. Fishery Resources
 - 22. Fish present
 - 23. Fisheries management plans
 - 24. Angler use
 - 25. Commercial fishery
 - 26. Substrate types
 - 27. Key habitat areas
 - F. Wildlife resources
 - 28. Wildlife present
 - 29. Key habitat areas
 - 30. Wildlife management plans
 - 31. Wildlife use (i.e., deer yards; breeding, resting, feeding areas; etc.)
 - 32. Commercial use (trapping, fishing, etc.)
-

Information is the key to proper scoping. The biologist must ask if there is enough information available to really understand the implications of the project. For example, if new dam construction is involved, project information should make clear where the construction materials are coming from, where and how construction equipment and material will be stored, the details of construction schedules, and what specific measures for controlling erosion and sediment the developer is committed to undertake. Often, adequate information concerning the details of construction has not been provided, or site specific physical, chemical and biological data are missing, thus making it difficult to assess project impacts and establish meaningful terms and conditions for minimum instream flow.

The biologist must have a high degree of knowledge concerning life histories and habitat requirements for species which are considered to be important in the region. The biologist must identify potential conflicts with Federal and State resource management plans, as well as resource goals and policies. For example, in New England, the restoration of Atlantic Salmon is a resource goal, and specific management plans have been developed on Federal and State levels to achieve this goal. It is essential for both the biologist and the developer to be aware of such plans and to have some sense of the importance of one as compared to another. It must be recognized that one goal and its associated management plans may conflict with another and, therefore, it may be necessary to rank goals. For example, free flowing rivers provide maximum benefit to Atlantic Salmon but perhaps not to some other species, which favor a marsh habitat, and are also the subject of the management plan.

8.5 MEETING INFORMATION NEEDS

There are several sources of information about SSH projects and their potential impacts. The developer's proposal is the best basis for information about what is to be done at the site; additional contacts with the developer may be necessary to clarify some points. This manual describes many aspects of SSH technology that may not be mentioned in the proposal, but that should be known to persons involved in impact assessment. U.S. Geological Survey topographic maps or aerial photographs can be very informative for a basic understanding of the project's relationship to existing habitats. A site visit also is helpful. Government agency personnel at Federal, State, and local levels may have critical information on such factors as stream flow, climate, water rights claims, prior uses of the site, and other new developments proposed or in progress within the drainage basin.

Once the facts about the proposed project are fairly complete, an assessment of potential impacts can be made. Comparison of the potential impacts listed in Tables 12 and 13 with the known features of the project and the site will help determine which impacts are unlikely and which should be explored further with the developer, experts in particular subjects, or by literature review. It is desirable to indicate the predicted severity of the anticipated impacts. A checklist, such as the following, can be used for this purpose:

Impact	Severity			
	Major	Moderate	Minor	None
Turbine mortality	_____	_____	_____	_____
Fish injury by impingement	_____	_____	_____	_____
Dewatering of stream	_____	_____	_____	_____
Removal of vegetation	_____	_____	_____	_____

If it is difficult to assign a level of severity to an impact when going through a checklist of this type, more information is needed. A more thorough search of the literature may reveal the data necessary or it may be necessary for the developer to perform additional site specific studies (such as an instream flow analysis). For turbine mortality, it may be necessary to permit the project on a conditional basis subject to the results of monitoring studies.

8.6 COMPLEX IMPACT INTERRELATIONSHIPS

At this stage, the biologist probably should re-check the list of anticipated impacts to ensure that none are missed, especially indirect or delayed impacts, which can be easily overlooked. Some impacts may not be readily apparent from simply comparing the list of proposed developer actions with a list of known SSH impacts, such as those in Table 12. Some examples of the complex relationships that are possible among impacts are given in the next few paragraphs. This discussion is by no means exhaustive. Careful thinking about individual SSH projects under study will undoubtedly lead to a greater understanding of the subtleties of impact assessment.

Environmental impacts often occur as a chain of causes and effects; the effects of some impacts (primary impacts) become the causes of others (secondary impacts). For example, reducing the sediment load downstream when a river is dammed has the primary impact of making the stream bottom too coarse for many mud- and sand-dwelling invertebrates. Fish that depend on these species for food suffer progressive population depletion as their food supply declines. The resource manager may not be concerned with invertebrates per se and may, therefore, decide that the impact of habitat reduction is not of concern. However, this oversight can result in the eventual loss of the fish resource.

Another class of impacts that may be overlooked are long term impacts, especially if these impacts are secondary. For example, impoundments on rivers with a heavy silt load typically trap much of the suspended sediment and may lose significant storage capacity well before the planned economic life of the SSH project is over. The solution to this problem is to dredge the reservoir or to flush it by opening deep gates and washing the

accumulated sediment downstream. The impacts of severe siltation downstream, which may include the clogging of small sidestreams, increased flooding, injury to fish and wildlife, and destruction of wetlands, are not immediate impacts of SSH activities, but are long term consequences of the combination of SSH development with a high suspended sediment load.

Some impacts, when considered individually, seem to have insignificant effects on resources. However, the total impact is severe when cumulative effects at several sites or of repeated occurrences are considered. The impact of several turbine passages on fish was illustrated in Figure 40. Another example is water quality. If an existing dam discharges water critically low in dissolved oxygen from time to time, causing occasional fish kills, a proposal to add a second dam above it should be looked at carefully in terms of cumulative impact. The new upstream dam might also reduce downstream dissolved oxygen, so that the conditions existing below the original dam are greatly extended. Or, dissolved oxygen in the original reservoir can become so low that toxic pollutants are mobilized from sediments, further decreasing water quality, but in a different way.

Synergistic relationships in which the combined effects of two or more factors is greater than the simple addition of their separate impacts are potentially very important. The effects of turbine mortality and predation at a hydro site illustrate synergistic impacts. Fish that survive turbine passage may be weakened, but not killed and if given time to recover, could continue emigrating. Similarly, fish passing directly through the tailwater avoid predation and proceed downstream safely. However, fish that are delayed in the tailwater due to stunning during turbine passage are more subject to predation and experience higher mortality rates. Thus, the combination of two comparatively modest impacts has an effect much greater than the simple addition of both.

One reason it is difficult to predict the impact of SSH development is because so much depends on the characteristics of the site chosen. For example, consider the hypothetical valley section illustrated in Figure 47, which includes an existing run-of-river hydro plant, the remains of a navigation canal abandoned in 1927, and various railway rights-of-way and sidings. The check dam that formerly maintained the water level for the canal has resulted in the development of swamps in an area that was formerly a reservoir. The comparative inaccessibility of the site and the stable water levels in the old canal, which extends six km, have made this valley an important shelter for wildlife, particularly fur bearers and birds.

A developer proposes to add a SSH plant to the old check dam, including some excavation of the site to increase pondage above the dam. The same developer rehabilitated the hydro plant just downstream from this site and installed a fish ladder at that time, permitting shad and herring as far upstream as the dam that will be used in the new project. A number of questions are appropriate concerning this new installation.

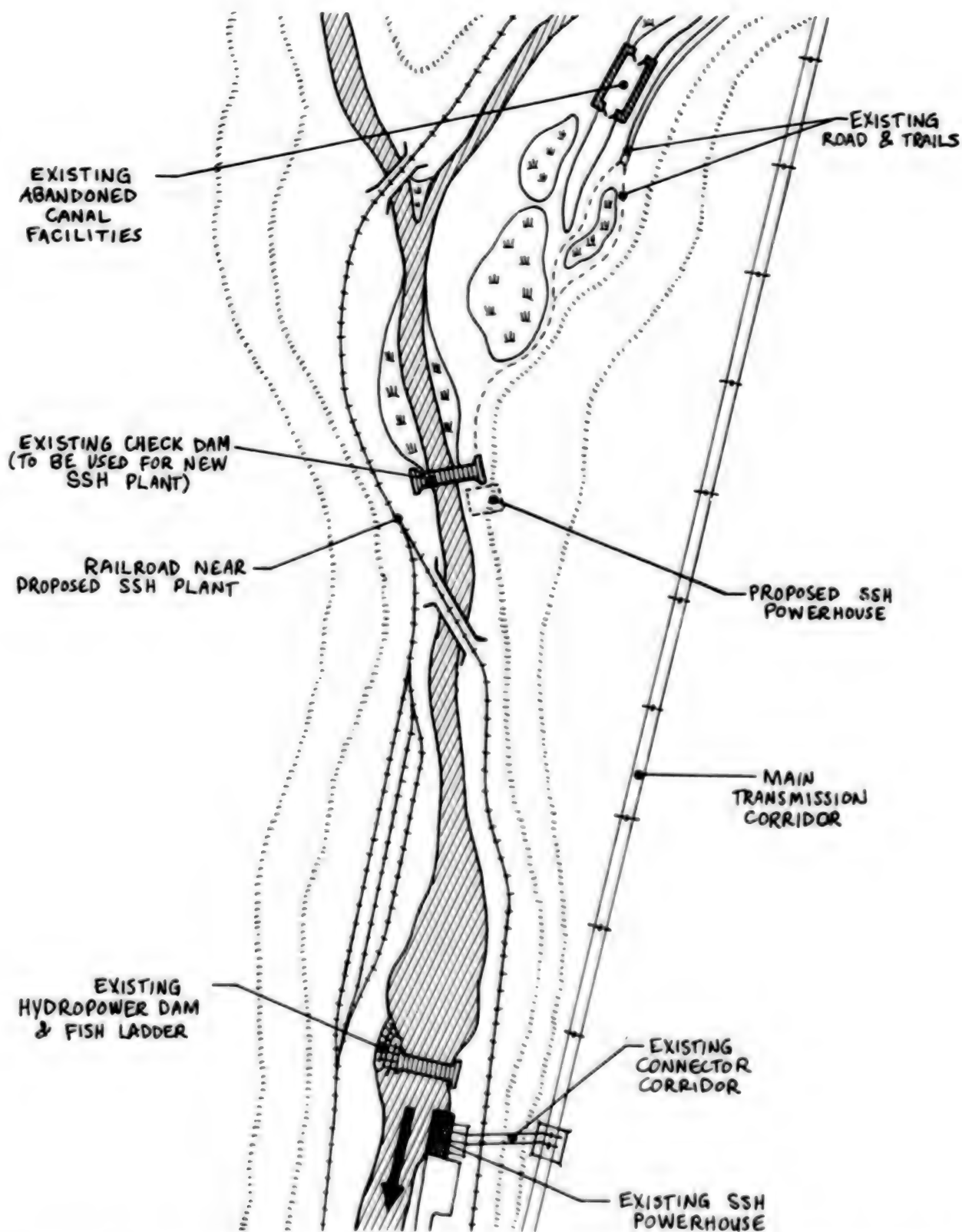


Figure 47. Hypothetical reach of river, showing locations of hydroelectric and other facilities (T. Lloyd Associates).

- How much excavation is intended, and how will this change the character of the wetlands above the check dam?
- How much additional anadromous fish habitat will be available if a fish passage device is added to the check dam as a condition for permitting installation of the new SSH plant?
- Is the lake that will be created likely to stratify in summer, and, if so, what are the likely effects of possible changes in the temperature regime in the reach between the two dams?
- What will be done with the spoil created by excavating the reservoir? Will new access roads be needed to transport this material?
- Will it be necessary to move the railroad tracks (either because of the SSH project itself or the possible fish ladder), and, if so, what additional construction activities will be involved?
- Will the proposed powerhouse site require excavation and filling along the streambank below the dam?
- Is the proposed operation plan for the new SSH plant likely to conflict with the established operations of the existing plant or with the fish ladder?
- Does the potential exist for water quality problems to develop in the reach between the two dams, thus creating a barrier to fish movement and nullifying any benefits from upstream mitigation efforts?
- How will extending fish runs above the check dam affect fishing opportunities overall in the region? Will fishing pressure increase?
- What instream flow releases will be required from the new SSH plant to maintain present habitat?

Not all SSH projects proposed are in areas as highly developed as the one described here, but there are very few sites in the United States where SSH impacts can be considered in isolation from impacts from other sources.

8.7 ASSIGNING PRIORITIES TO IMPACTS

Attention should be focused on the most important impacts as a first step in the identification of environmental impacts needing management action. It is essential to assign priority to impacts in order to avoid wasting time and effort on impacts that are insignificant or perhaps not likely to occur at all.

Each environmental impact, whether on water quality, fish passage, bird habitat, or other environmental topic, has an absolute magnitude (severity), which is determined by the strength of the causative agent and the susceptibility of the affected environmental feature. An estimate of 250 birds per year killed by collision with transmission lines at a particular site is an example of a specific impact magnitude. However, this level of impact may be relatively insignificant if there are tens of thousands of birds using the site, if the existing food supply is barely sufficient for current levels of bird use, or if hunters are permitted to take hundreds of birds annually at the same site.

Thus, to assign importance to impacts one must understand the nature of the site from the point of view of fish, wildlife, and their habitats. Particularly, it is important to keep in mind overall resource goals and specific objectives for the site. For example, in New England the Atlantic salmon is making a comeback with the aid of a management program, but some rivers remain inaccessible to salmon due to dams or pollution. A SSH project on one of the rivers where salmon have not yet become reestablished should be viewed as having a potential future impact on the goal of salmon restoration, even though it currently does not block fish. That is, salmon runs should be taken into account when assigning importance to the impact of fish migration blockage.

Assigning priorities to SSH impacts has two main uses:

1. It allows one to work with the most important impacts first, which means that in choosing alternatives or recommending mitigation, attention will be devoted to the impacts with the greatest potential for harming fish and wildlife.
2. It prevents one from becoming preoccupied with the impacts of greatest severity, which may not be the same as those impacts of greatest management priority. For example, if one emphasizes fish passage over concern about short-range movements of nonanadromous fish, but ignores water quality, it could turn out that seasonal deep releases of deoxygenated water would kill the fish before they reach the passage equipment.

Ideally, the impact assessment process should result in a list of impacts of the greatest importance to fish and wildlife management objectives. When this list has been finalized, possible alternatives and mitigation actions can be considered.

8.8 CONSIDERING ALTERNATIVES

8.8.1 Mitigation Measures

Once the extent and nature of the environmental impacts of the SSH project are known, mitigation actions can be planned. FWS biologists have

specific guidelines for developing mitigation plans as specified in the U.S. Fish and Wildlife Service Mitigation Policy. Mitigation as defined in this National Environmental Policy Act includes:

- avoiding the impact altogether by not taking a certain action or parts of an action;
- minimizing the impacts by limiting the degree or magnitude of the action and its implementation;
- rectifying the impact by repairing, rehabilitating and restoring the affected environment;
- reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; and
- compensating for the impact by replacing or providing substitute resources or environments (40 CFR Part 1508.20 (a-e)).

Specific mitigation techniques reflecting all five approaches to mitigation are described in the Mitigation Handbook.

In summary, the ultimate goal of impact assessment and mitigation planning as applied to SSH development is to maximize the fish, wildlife and wetland/riparian benefits of SSH projects while minimizing negative project impacts. This is not easy, both because of engineering and economic constraints and because, in many instances, data on the magnitude of impacts is inadequate. Cooperation among resource managers, SSH project developers, and other persons interested in river assets is the approach most likely to assure maximum benefits for all.

GLOSSARY

afterbay - The body of water immediately downstream from a hydroelectric plant. see tailrace.

air valve - A device that automatically admits or releases air from a pipeline without permitting a loss of water.

appraisal study - A preliminary feasibility study to determine if a detailed feasibility study is warranted. Also called a reconnaissance study.

apron (of a dam) - A floor or lining to protect a surface from erosion; for example, the pavement below chutes, spillways, or at the toe of a dam.

attraction waters - Generation or pumping flows that attract fish.

average-water year - The average annual flow of water available for hydropower generation calculated over a long period, usually 10 to 50 years.

bank storage - Water absorbed by the bed and banks of a stream, reservoir, or channel, and returned, in whole or part, as the water level falls.

base load - The minimum amount of electric power that is needed at all times all times and all seasons.

bus bar - 1. A conductor forming a common junction between two or more electrical circuits. 2. A term commonly used in the electric utility industry to refer to electric power leaving a station boundary. Also known as a bus.

bus bar costs - The cost per unit of electric energy leaving the station.

butterfly valve - A circular valve inside a penstock or other conduit. May be used as a head gate and is commonly placed in the penstock just before the entrance to the turbine. Unlike wicket gates, butterfly valves may be watertight when the turbine is shut down and the valve closed, thus ensuring that the water power behind the valve will be immediately available when the valve is reopened.

capacity - 1. The maximum power output. 2. The load for which a unit, generating station, or other electrical apparatus is rated. Common units include kilovolt-ampere (kVA), kilowatt (kW), and megawatt (MW).

cavitation - Violent collapse of bubbles of water vapor that may form in the vacuum normally found at local points within the runner and draft tube. Occurrence of cavitation depends on atmospheric pressure, hydrostatic pressure, water temperature, water velocity, and directional changes. Cavitation breaks down the surface of metal objects, encouraging oxidation, and, in severe cases, results in the development of a honeycomb structure in the metal.

cofferdam - A temporary, watertight enclosure from which the water is pumped in order to expose the bottom of a body of water and, thus, permit construction.

crest - The top edge of a dam, dike, spillway, or weir, frequently referring specifically to the overflow portion.

critical head - The head at which the output of a turbine operating at full capacity equals the nameplate rating of an associated generator.

critical stream flow - The amount of water available for hydroelectric power generation during the most adverse streamflow period.

dam - A barrier to confine or raise water for storage or diversion or to create a hydraulic head.

demand (electrical) - The rate at which electric energy is delivered to or by a system, part of a system, or piece of equipment, expressed in kilowatts or other suitable units, at a given instant or average over any designated period of time.

design head - The head at which the turbine is designed to give the best overall efficiency under various operating conditions.

diversion structure - A partial obstruction of a free flowing stream used to divert water for some purpose.

draft tube - A tube that takes the water discharged from a turbine at a high velocity and reduces its velocity by enlarging the cross sectional area of the tube. The water is released to the tailrace.

drawdown - The distance that the water surface of a reservoir is lowered from a given elevation as the result of the withdrawal of water.

edge effect - The increase of wildlife resulting from simultaneous access to more than one type of habitat or to greater richness of border vegetation.

energy dissipater - A device used to reduce water pressure or velocity to a safe level.

entrainment - 1. The process by which a stream of water and its dissolved and suspended contents attracts and drags along peripheral water. 2. The pulling in and subsequent transport of organisms or particles in an entrained fluid, as at the entrance to a power plant intake.

Federal Energy Regulatory Commission (FERC) - An agency, in the U.S Department of Energy, that licenses non-Federal hydropower projects and regulates the interstate transfer of electrical energy.

firm capacity - Capacity of a plant that can be guaranteed to meet load requirements.

firm load - That part of the system load that must be met with firm power.

firm power - Power needed to ensure power availability to meet load requirements.

fish passage facility - A device to enable fish to pass around or over a dam or other obstruction.

fish screen - A porous barrier placed across the inlet or outlet of a pond to prevent the passage of fish.

flashboard - A board placed across the top of a spillway and used to raise or lower water levels behind a dam.

flow-duration curve - A graphic presentation of flow values plotted in descending order of magnitude against the percentage of time that a particular flow is equaled or exceeded.

flow line - The point at which a free flowing stream meets a reservoir pool.

forebay - That part of the impoundment or headwater immediately above the dam or power plant intake structure.

Francis turbine - A reaction turbine that uses the combined action of the pressure and velocity of the water to drive generating equipment. Water enters the unit radially and leaves axially.

gate - A structure or device for controlling the rate of water flow into or from a canal, ditch, or pipe (see headgate).

Generating capacity - The maximum load that the system can generate under specified conditions for a given time interval without exceeding approved limits of temperature and stress.

generator - A machine that converts mechanical energy into electrical energy.

glory hole spillway - A vertical shaft having a funnel-shaped entrance and ending in an outlet tunnel that provides an overflow from a reservoir. Also called morning glory spillway or shaft spillway.

gross head - The difference in elevation between the headwater surface above the dam and the tailwater surface below a hydroelectric powerplant under specified conditions.

guide vanes - Moveable guide vanes (sometimes called wicket gates) control the amount of flow to the turbine runner. They can be closed to shut off flow to the turbine (with varying amounts of leakage) or opened to admit flow. They also impart a spin to the flowing water so that it acts more efficiently on the runner blades.

head - See hydraulic head.

headgate - A water control structure. The gate at the entrance to a conduit.

hydraulic capacity - The maximum flow that a hydroelectric plant can use for power generation.

hydraulic head - 1. The difference in hydraulic pressure between two points, expressed in terms of the vertical height of a column of water that has the same pressure difference. 2. The elevation between the headwater surface above the dam and the tailwater surface below a hydroelectric powerplant.

hydraulic jump - A sudden turbulent rise in water level, such as often occurs at the foot of a spillway when the velocity of rapidly flowing water is instantaneously slowed.

impulse turbine - A turbine that operates with high pressure jets discharging freely into the atmosphere against bowl-shaped buckets on the runner. The impulse turbine in most common use is the Pelton wheel.

installed capacity - The total of the capacities shown on the nameplates of the generating units in a hydropower plant (see nameplate capacity).

intake or intake structure - A structure through which the water from the reservoir or head race enters the power generating facility, penstock, or other conduit. It usually contains trash racks and often screens.

Kaplan turbine - A hydraulic turbine using a propeller-type runner and wicket gates in which the pitch of the propeller blades and wicket gates is adjustable under load to achieve optimum performance in the generation of hydroelectric power. Most frequently used in the low-to moderate-head range.

kilowatt (kw). - One thousand watts (W) or 1.34 horsepower (hp).

kilowatthour (kWh) - 1. One thousand watthours (Wh). 2. The amount of electrical energy produced or consumed by 1 kw unit for one hour; the basic unit of electric energy.

load - 1. The amount of power needed to be delivered at a given point on an electric system. 2. The rate at which electric energy is delivered to or by a system or to a piece of equipment, expressed in kilowatts, kilovolt-amperes, or other suitable unit at a given instant or averaged over any designated period of time. 3. The amount of electrical energy delivered or required at a given point in a system.

megawatt (MW) - One thousand kilowatts or one million watts.

morning glory spillway - see glory hole spillway.

multiple-purpose installation - A facility that serves more than one function, such as hydroelectric power, irrigation, water supply, water quality control, flood control, or fish and wildlife enhancement.

nameplate capacity - The nominal rated capacity of a generator or other similar apparatus. The term gives an indication of the approximate generating capacity of the unit; however, in many cases, the unit is capable of generating substantially more than the nameplate capacity on a continuous basis.

nameplate rating - The full load continuous rating of a generator or other piece of electrical equipment under specified conditions, as designated by the manufacturer and written on the nameplate.

net head - The gross head less all hydraulic losses except those attributable to the turbine.

operating range - The range of hydraulic head and flow existing during operation of a hydroelectric plant, within which the turbine can be operated without undue vibration or cavitation drainage.

peaking capability - The maximum peak load that can be supplied by a generating unit, station, or system in a stated time period. For a hydroelectric project, the peaking capability equals the maximum plant capability under favorable pool and flow conditions.

peaking capacity - Generating capacity during the highest daily, weekly, or seasonal loads. Some generating equipment may be operated at certain times at peaking capacity and at other times to serve loads on a round-the-clock basis.

peaking plant - A power plant that is normally operated to provide all or most of its generation during maximum load periods. Also called peak-load plant.

peaking unit - An auxiliary electric power system that is used to supplement the power supply system during periods of peak demand for electricity.

peakload (peak load) - The greatest of all load demands on an interconnected electric transmission network occurring during a specified time period.

peak-load plant - See peaking plant.

pelton turbine - A hydraulic turbine in which the energy of water is converted through nozzles into high velocity jets of water. This drives the turbine by the force the water jets exert on buckets attached to the turbine wheel. Also known as impulse turbines, they are generally used in high head operations.

penstock - Pipe or other enclosed conduit carrying water under pressure from the dam to a turbine.

pondage - The storage of sufficient amounts of water for daily or weekly regulation of flow. Generally applies to storage at run-of-river plants.

power drop - A tube or trough that conveys water to a power plant and takes advantage of a drop in elevation to provide head and velocity for operating the turbine.

power-transfer capacity - The maximum power or load that can be transferred from one point to another over electric power transmission facilities.

prime energy - Hydroelectric energy that is assumed to be available 100% of the time; specifically, the average energy generated during the critical period.

propeller turbine - A reaction turbine with either adjustable or fixed blades; propeller turbines are generally used for hydro projects with a lower head.

reaction turbine - A bladed turbine that operates full of water, with water under pressure flowing through and turning the blades.

rehabilitation - The restoration of an abandoned power plant for the production of energy.

reregulating reservoir - A reservoir, located downstream from a hydroelectric peaking plant, that has sufficient pondage to store the widely fluctuating discharges from the peaking plant and release them downstream in a relatively uniform manner.

reserve generating capacity - Extra generating capacity available to meet unanticipated demands for power or to generate power in the event of loss of regularly used generating capacity. Reserve capacity to meet the latter is also known as forced outage reserve.

reserve system capacity - The difference between the dependable capacity of the system, including net firm power purchases, and the actual or anticipated peak load for a specified period.

retention time - Time (usually days) required for a volume of water equal to the reservoir capacity to move through the reservoir and be discharged downstream.

retrofitting - Furnishing a plant with new parts or equipment not purchased or available at the time of construction. In hydropower development, the term may refer to the installation of electric generating components at existing water facilities.

return flow - That portion of the water diverted from a stream that finds its way back to the stream channel either as surface or underground flow.

reversible turbine - A hydraulic turbine that can be used alternatively as a pump or a prime mover; sometimes referred to as a pump-turbine.

revetment - A facing of masonry or concrete, used to protect an embankment from erosion or slumping.

riparian rights - The rights of a land owner to the water on or bordering his or her property, including the right to prevent diversion or misuse of upstream water.

runner - The part of a turbine, consisting of blades on a wheel or hub, that is turned by the pressure of high velocity water, thereby transforming falling water energy into rotating mechanical energy.

run-of-river plant - A hydropower plant that uses the flow of a stream with little or no reservoir capacity for storing water. Some run-of-river plants have limited storage capacity (pondage), which allows for stream-flow regulation on a daily or weekly basis.

scroll case - A spiral casing, made of steel or concrete, that carries water around the periphery of a turbine. As the water spirals in and is discharged through the wicket gates to the runner, the diameter of the scroll case decreases to keep the flow velocity uniform.

seasonal storage - Storage of water in a reservoir during that portion of the year when a surplus occurs.

shaft spillway - See glory hole spillway.

spillway - A passage used for running surplus water over or around a dam.

stilling basin - A structure located below the spillway or outlet that works to dissipate the energy of spilled or released water.

storage project - A project with a reservoir of sufficient size to permit carry over from the high flow season to the low flow season and, thus, develop a firm flow that is substantially greater than the minimum natural flow. A storage project may have its own power plant or may be used only for increasing generation at a downstream plant (see also seasonal storage).

stratified reservoir - A reservoir in which the the surface (epilimnial) water and the deep (hypolimnial) water do not mix because of density differences between the two layers.

submergence - The distance that a turbine or pump must be located below the minimum tailwater level; established primarily to prevent cavitation.

surge tank - A water chamber designed to reduce the dynamic effects of flow water-hammer pressures through long water conduits. Surge tanks are commonly located on the penstocks of hydroelectric plants.

system reserve capacity - The difference between the available, dependable capacity of the system, including net firm power purchases, and the actual or anticipated peak load for a specified period.

tailrace - The channel, downstream of the draft tube, that carries the water discharged from the turbine. Sometimes called the afterbay.

tailwater - 1. Water in a river or canal immediately downstream from a structure such as a dam or hydroelectric power plant. 2. Energized water that has passed the dam but is still under the influence of velocity and a change in elevation.

take line - The property boundary or control line that encompasses lands acquired for project use, usually around the reservoir.

toe (of a dam) - The downstream, lower edge or edges of a dam structure.

toe wall - The downstream wall of a dam structure.

transmission grid - An interconnected system of electric transmission lines and associated equipment for the movement or transfer of electric energy in bulk between points of supply and demand.

transmission line - The system comprised of support structure, conductors, and insulators designed to carry large blocks of electrical energy from one point to another at a voltage of 60 kV or above. The energy is transmitted from generating stations, between points of interchange, and between transmission substations to distribution substations or to individual customers. Generally the voltages involved are 60 kV, 70 kV, 115 kV, 230 kV, or 500 kV.

trash rack - A grid, coarse screen, or heavy vertical bar placed across a water inlet to catch floating debris.

trash rake - A mechanism used to clean the trash rack.

traveling screen - A revolving trash screen, having a small mesh, usually 3/8 inch square, situated plantward of the trash bar racks. The traveling screen moves on endless, oval tracks and is usually operated at regular intervals or is pressure sensitive and operates only when activated by the pressure of impinged organisms. It is often equipped with spray jets inside the face of the screen to wash impinged material from the outside face into trash collection troughs.

turbine - A rotary machine in which the pressure or kinetic energy of flowing water is converted to mechanical energy that, in turn, can be converted to electrical energy by a generator (see also propeller turbine, Francis turbine, impulse turbine, pelton turbine).

ultralow head - Head of up to 3 meters (9.8 ft.).

utility corridor - A strip of land containing more than one transmission line, pipe line, canal, road, or other linear feature in joint use.

water-dependent - The dependency of an activity or projects on a location in, on, or immediately adjoining a navigable water, usually not merely for the consumptive use of water.

water diversion - An act or facility for taking water away from a water body.

wicket gates - A series of overlapping, adjustable guide vanes placed around the circumference of a turbine to regulate the amount of water passing through the turbine and, consequently, controlling the output of the hydroelectric unit.

yield - The amount of water that can be supplied from a reservoir or a water source in a specified time period.

APPENDIX

CONVERSION FACTORS USEFUL IN SMALL-SCALE HYDROELECTRIC TECHNOLOGY

Quantity	Metric Unit	English Unit	To convert metric unit to English unit, multiply metric unit by:	To convert English unit to metric unit, multiply English unit by:
Length	millimeters (mm)	inches (in)	0.03937	25.4
	centimeters (cm)	inches	0.3937	2.54
	meters (m)	feet (ft)	3.2808	0.3048
	kilometers (km)	miles (mi)	0.62139	1.6093
Area	square millimeters (mm ²)	square inches (in ²)	0.00155	645.16
	square meters (m ²)	square feet (ft ²)	10.764	0.092903
	hectares (ha)	acres (ac)	2.4710	0.40469
	square kilometers (km ²)	square miles (mi ²)	0.3861	2.590
Volume	liters (l)	gallons (gal)	0.26417	3.7854
	cubic meters (m ³)	cubic feet (ft ³)	35.315	0.028317
	cubic meters (m ³)	cubic yards (yd ³)	1.308	0.76455
	cubic decameters (dam ³)	acre-feet (ac-ft) ^a	0.8107	1.2335
Weight	kilograms (kg)	pounds (lb)	2.2046	0.45359
	metric ton (MT)	tons, short (T)	1.1023	0.90718
Power	kilowatts (kW)	horsepower (hp)	1.3405	0.746
Velocity	centimeters per second (cm/s)	inches per second (in/s)	0.3937	2.54
	meters per second (m/s)	feet per second (fps)	3.2808	0.3048
Discharge	cubic meters per second (m ³ /s)	cubic feet per second (cfs)	35.315	0.28317
	liters per minute (l/min)	gallons per minute (gal/min)	0.26417	3.7854
	liters per day (l/day)	gallons per day (gal/day)	0.26417	3.7854
	megaliters per day (ML/day)	million gallons per day (mgd)	0.26417	3.7854
	cubic decameters per day (dam ³ /day)	acre-feet per day (ac-ft/day)	0.8107	1.2335

^a1 acre-foot = 325,851 US gallons.

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